UNIVERSITY OF HELSINKI
FACULTY OF BIOLOGICAL AND ENVIRONMENTAL SCIENCES

VOLUNTARY BIODIVERSITY CONSERVATION OPTIMIZATION IN AGRICULTURAL AND FOREST ENVIRONMENTS

ANNIKA HARLIO

Voluntary biodiversity conservation optimization in agricultural and forest environments

ANNIKA HARLIO

LUOVA
Doctoral Programme in Wildlife Biology Research

Department of Biosciences
Faculty of Biological and Environmental Sciences
University of Helsinki
Finland

LICENCIATE THESIS
Helsinki 2017

SUPERVISED BY: Dr. Anni Arponen
Metapopulation Research Centre
Department of Biosciences
University of Helsinki, Finland

Dr. Mikko Kuussaari
Finnish Environment Institute (SYKE)
Natural Environment Centre
Helsinki, Finland

EXAMINED BY: Panu Halme, University of Jyväskylä
Reija Hietala, University of Turku

MEMBERS OF THE THESIS ADVISORY COMMITTEE:

Dr. Irina Herzon
Dept. of Agriculture Sciences
University of Helsinki, Finland

Dr. Terho Hyvönen
Natural Resources Institute Finland
Jokioinen, Finland

Dr. Minna Kaljonen
Finnish Environment Institute
Helsinki, Finland

Prof. Tomas Roslin
Department of Ecology
Swedish University of Agricultural Sciences
750 07 Uppsala, Sweden

ISBN 978-951-51-3617-6 (Paperback)
ISBN 978-951-51-3618-3 (PDF)

Electronic publication at http://ethesis.helsinki.fi

Unigrafia
Helsinki 2017

CONTENTS

The thesis constitutes of the following articles, which are referred to in the text by their Roman numerals:

I **Harlio, A.,** Kuussaari, M., Heikkinen Risto, K., Arponen. A. (2017). Biodiversity conservation of semi-natural grasslands profits from a multi-objective and broader scale spatial optimization approach. In review.

II Paloniemi, R., Hujala, T., Rantala, S., **Harlio, A**., Salomaa, A., Primmer, E., Pynnönen, S., Arponen, A. (2017). Integrating social and ecological knowledge for targeting voluntary biodiversity conservation. Conservation Letters. Accepted 23 December 2016, DOI: 10.1111/conl.12340.

Table of contributions

	I	II
Original idea	AA, MK	AA, RP
Design	AA, AH	AA, RP, TH
Data collection	AH	*AH, SP, AS
Analyses	AH	*AH, SP, AS, RP
Manuscript preparation	AH, AA, MK, RKH	RP, TH, SR, AH AS, EP, SP, AA
AH: Annika Harlio	RP: Riikka Paloniemi	SR: Salla Rantala
AA: Anni Arponen	TH: Teppo Hujala	EP: Eeva Primmer
MK: Mikko Kuussaari	SP: Sari Pynnönen	
RKH: Risto K. Heikkinen	AS: Anna Salomaa	

* Chapter II consisted of three different data and analysis sets. Annika Harlio was responsible for data collection and analysis of the Zonation section, Sari Pynnönen was responsible for data collection and analysis of the landowner survey, Riikka Paloniemi carried out the factor analysis on the survey and Anna Salomaa was responsible for data collection and analysis of the workshop discussions. Annika Harlio assisted in forming the landowner survey statements and was responsible for processing them into spatial format for Zonation prioritization. Annika Harlio participated in data collection of the workshop discussions. Annika Harlio carried out writing of most of the Zonation sections in the manuscript.

Tiedekunta – Fakultet – Faculty Faculty of Biological and Environmental Sciences		Laitos – Institution– Department Department of Biosciences
Tekijä – Författare – Author Annika Harlio		
Työn nimi – Arbetets titel – Title Voluntary biodiversity conservation optimization in agricultural and forest environments		
Oppiaine – Läroämne – Subject Ecology and Evolutionary Biology		
Työn laji – Arbetets art – Level Licenciate Thesis	Aika – Datum – Month and year August 2017	Sivumäärä – Sidoantal – Number of pages 87

ABSTRACT

Agriculture and forestry comprise 75% of all land uses in Europe, which causes conflicts with natural resource conservation. This intensive land use has been observed internationally as declining habitats and species biodiversity loss trends. The challenge of conserving biodiversity while simultaneously using land for production has brought about a framework that distinguishes between the separation, ”land sparing”, and the integration, ”land sharing”, of conservation and production.

Setting public land aside as “land sparing” is insufficient to fulfil the biodiversity targets of international conventions. Thus, protecting biodiversity on private agricultural and forestland is critical for effective biodiversity conservation, which raises socio-political aspects to an integral role in the conservation planning process. As ecological and economic resources for nature conservation are limited, conservation efforts must be prioritized to achieve best possible outcomes. In this thesis, in addition to the land-sparing/sharing approach, I applied two policy-based conservation strategies based on the voluntary participation of landowners, alternative biodiversity conservation activities within the EU’s Common Agricultural Policy and Finnish Forest Biodiversity Programme METSO, to demonstrate how social and ecological data could be integrated into multi-objective spatial conservation prioritization using Zonation software.

This thesis is based on two chapters building on spatial optimization, one manuscript and one article published in a peer-reviewed scientific journal: i) **Harlio, A.,** Kuussaari, M., Heikkinen Risto, K., Arponen. A. (2017*). Biodiversity conservation of semi-natural grasslands profits from a multi-objective and broader scale spatial optimization approach*. In review, manuscript, and ii) Paloniemi, R., Hujala, T., Rantala, S., Harlio, A., Salomaa, A., Primmer, E., Pynnönen, S., Arponen, A. (2017). *Integrating social and ecological knowledge for targeting voluntary biodiversity conservation*. Conservation Letters. Accepted 23 December 2016.

My thesis produced new information on how multiple landscape heterogeneity elements and landowner perceptions in conservation prioritization caused trade-offs between various biodiversity objectives. In multi-functional landscapes, such as agricultural environments, we found landscape-level clustering of small and valuable semi-natural grassland habitats (“land sparing”) with other biodiversity-rich elements receiving agri-environment payments in the area (“land sharing”). These areas also maintained better connectivity, which enhances the dispersal capability of grassland species. Ecological targets had to be compromised in forest environments when landowner perceptions were accounted for.

Recognition of these potentially contradictory targets is important during a wider conservation planning process, so that conservation prioritization is able to provide alternative solutions for consideration in the planning process and improve biodiversity conservation effectiveness. The results of this thesis may help regional environmental authorities allocate limited conservation funding to socially acceptable and ecologically valuable areas.

Avainsanat – Nyckelord – Keywords agricultural environments, biodiversity conservation, Common Agricultural Policy, conservation planning, Finnish Forest Biodiversity Programme METSO, forests, landscape ecology, GIS, Zonation
Ohjaaja tai ohjaajat – Handledare – Supervisor or supervisors Anni Arponen, Mikko Kuussaari
Säilytyspaikka – Förvaringställe – Where deposited Helsinki University Library
Muita tietoja – Övriga uppgifter – Additional information

Tiedekunta – Fakultet – Faculty
Bio- ja ympäristötieteellinen tiedekunta

Laitos – Institution– Department
Biotieteiden laitos

Tekijä – Författare – Author
Annika Harlio

Työn nimi – Arbetets titel – Title
Voluntary biodiversity conservation optimization in agricultural and forest environments

Oppiaine – Läroämne – Subject
Ekologia ja evoluutiobiologia

Työn laji – Arbetets art – Level
Lisensiaattitutkielma

Aika – Datum – Month and year
Elokuu 2017

Sivumäärä – Sidoantal – Number of pages
87

TIIVISTELMÄ

Luonnonvarojen käyttö aiheuttaa ristiriitoja etenkin Euroopan Unionin alueella, missä maataloustuotanto ja metsäelinkeino vievät 75 % Euroopan maapinta-alasta. Intensiivinen maankäyttö ihmisen käyttötarpeisiin on johtanut elinympäristöjen ja lajien monimuotoisuuden merkittävään heikkenemiseen. Elinkeinoelämän tuotantovaatimusten ja luonnon monimuotoisuuden yhteensovittamisen ratkaisemiseksi on ehdotettu kahta eri lähestymistapaa: Erillisten suojelualueiden perustamista (”land sparing”) kokonaan erillään tehotuotannosta ja suojelun ja ympäristöystävällisemmän tuotannon yhdistämistä (”land sharing”).

Kansainvälisissä sopimuksissa sovitut luonnon monimuotoisuuden suojelutavoitteet eivät ole täyttyneet perustamalla pelkästään erillisiä suojelualueita julkisessa omistuksessa oleville maille. Siksi yksityisomistuksessa olevien maatalous- ja metsäelinympäristöjen ottaminen mukaan suojelusuunnittelutyöhön on tärkeää. Suunnittelua on tällöin tarkasteltava ekologisen näkökulman lisäksi myös sosio-poliittisesta näkökulmasta. Suojelukeinojen eri lähestymistapojen lisäksi sovelsin tässä tutkimuksessa suojelusuunnittelun pohjana kahta vapaaehtoisuuteen perustuvaa suojeluohjelmaa, EU:n maataloustukien vaihtoehtoisia monimuotoisuutta suojelevia toimenpiteitä ja Etelä-Suomen metsien monimuotoisuusohjelma METSOa. Hyödynsin niistä saatua ekologista ja sosiaalista tietoa paikkatietopohjaisessa Zonation-suojelusuunnitteluohjelmistossa, jotta luonnonsuojelun rajalliset voimavarat voitaisiin kohdentaa kustannustehokkaasti.

Tämä tutkimus perustuu kahteen suojeluoptimointia tarkastelevaan osajulkaisuun, yhteen käsikirjoituksen ja yhteen vertaisarvioituun julkaisuun: i) **Harlio, A.,** Kuussaari, M., Heikkinen Risto, K., Arponen. A. (2017). *Biodiversity conservation of semi-natural grasslands profits from a multi-objective and broader scale spatial optimization approach*. Käsikirjoitus, vertaisarvioinnissa, ja ii) Paloniemi, R., Hujala, T., Rantala, S., **Harlio, A**., Salomaa, A., Primmer, E., Pynnönen, S., Arponen, A. (2017). *Integrating social and ecological knowledge for targeting voluntary biodiversity conservation*. Conservation Letters. Hyväksytty 23.12.2016.

Osoitimme tutkimuksessa Zonation-ohjelmiston avulla, kuinka maisemarakenne ja maanomistajien asenteet rajoittivat suojelualueverkoston ekologisten tavoitteiden optimaalista toteutumista. Maatalousympäristöjen pienialaiset arvokkaat niittyalueet (”land sparing”) näyttivät kasautuvan alueille, joilla oli ympäröivää aluetta enemmän EU:n ympäristötukea saavia monimuotoisuuskohteita (”land sharing”). Näillä alueilla myös kohteiden kytkeytyvyys oli runsaampaa, mikä auttaa niittylajiston leviämistä kohteiden välillä. Kun maanomistajien asenne suojelutoimiin huomioitiin, ei saatu enää muodostettua ekologisesta näkökulmasta yhtä kattavaa metsien suojelualueverkostoa, mutta suojelutoimien hyväksyttävyys lisääntyi.

Suojelusuunnittelutyössä on tärkeää tunnistaa osin ristiriitaisiakin suojelutavoitteita, jolloin voidaan muodostaa vaihtoehtoisia suojelustrategioita kunkin alueen erityisiin tarpeisiin ja parantaa luonnon monimuotoisuustoimien vaikuttavuutta. Tutkimustulokset voivat auttaa alueellisia ympäristöviranomaisia kohdentamaan rajallista suojelurahoitusta maankäytön kannalta ristiriidattomiin, mutta ekologisesti mahdollisimman arvokkaisiin kohteisiin.

Avainsanat – Nyckelord – Keywords
Etelä-Suomen metsien monimuotoisuusohjelma METSO, EU:n yhteinen maatalouspolitiikka, GIS, monimuotoisuuden suojelu, maatalousympäristöt, maisemaekologia, metsät, paikkatieto, suojelusuunnittelu, Zonation

Ohjaaja tai ohjaajat – Handledare – Supervisor or supervisors
Anni Arponen, Mikko Kuussaari

Säilytyspaikka – Förvaringställe – Where deposited
Helsingin yliopiston kirjasto

Muita tietoja – Övriga uppgifter – Additional information

Annika Harlio

Metapopulation Research Centre, Department of Biosciences,

PO Box 65 (Viikinkaari 1), 00014 University of Helsinki, Finland

1. INTRODUCTION

1.1 Biodiversity loss in European agricultural and forest environments

Europe has one of the most intensively utilized land areas compared to other continents (EEA 2008). Agriculture and forestry comprise 75% of all land use in the European Union (EU) member states (Eurostat 2012). This causes inevitable conflicts with conservation and natural resource utilization.

The EU has identified agriculture, forestry and human-induced modifications on natural systems as the greatest pressures and threats to habitats and species biodiversity (EC 2015). This thesis focuses on finding solutions for biodiversity conservation that integrate natural resource management and socio-political settings.

Agriculture has been the primary human food source for thousands of years. Extensive use of semi-natural grasslands for cultivation and grazing provided biodiversity-rich landscape mosaics until the first half of the 20th century. Since then agricultural intensification has increased food production manifold, leading to an unforeseen population growth speed, currently reaching over 7 billion inhabitants globally (Godfray et al. 2010).

In consequence, intensified and modernized agricultural practices and associated landscape homogenization has led to the loss of up to 90% of semi-natural grassland habitats in Europe, which are endangered or threatened habitats in today's European agricultural ecosystems (Rassi et al. 2010; de Bello et al. 2010; Krauss et al. 2010; Auffret and Cousins 2011). According to EU assessments, only 12% of grassland habitats have a favourable conservation status (EC 2015). Nearly 50% of grassland-related bird species are declining, and the conservation status of other grassland species is mostly unfavourable (EC 2015). In Finland, 28% of threatened vascular plant species live in semi-natural grasslands (Rassi et al. 2010). According to the Finnish Ministry of the Environment (Vainio et al. 2001), the area of traditional semi-natural grasslands should be tripled to maintain the biodiversity provided by these biotopes in Finland.

The conservation status of forest habitats is not much higher than grasslands, as only 15% of them are regarded as favourable (EC 2015). Habitat loss, however, is not the primary reason for forest biodiversity loss as it is in agricultural environments. Commercial forest management significantly affects the biodiversity of forest habitats. Forests cover two-thirds of Finland's land area, but practically no forests remain in their natural state left (Kuuluvainen and Aakala 2011), as more than 90% of forested land is under commercial forest management (Peltola 2014). Consequently, 70% of forest habitats in Finland are considered threatened (Kontula and Raunio 2009), and 36% of threatened species are primarily forest species (Rassi et al. 2010).

This alarming biodiversity decline has not, however, remained unnoticed in international political decision-making. The United Nation's Convention on Biological Diversity (CBD) recognizes that global biological diversity is being significantly reduced by human activities (Juffe-Bignoli et al. 2014). The EU Biodiversity Strategy reflects these commitments, and aims to halt the loss of biodiversity and ecosystem services by 2020 (EC 2011). Over 90% of countries bound by the CBD have developed national biodiversity strategies and action plans, including Finland in 2012 (Juffe-Bignoli et al. 2014).

The CBD has recognized that conservation-oriented approaches alone do not lead to optimal conservation outcomes without acknowledging other influencing principles such as landscape context, adaptive management, stakeholder involvement or multiple spatial scales (Sayer et al. 2013). This thesis attempts to contribute to the challenge of integrating several landscape-level objectives and changing stakeholder perspectives while maximizing biodiversity benefits and maintaining the productive use of multi-functional agricultural and forest landscapes.

1.2 Land-sparing and land-sharing approaches in biodiversity conservation

The loss and fragmentation of habitats due to human land use is presently the single most important factor leading to biodiversity loss (Millenium Ecosystem Assessement 2005). The challenge of conserving biodiversity while simultaneously using land for production has raised a framework that distinguishes between the separation, ”land sparing”, and the integration, ”land sharing”, of conservation and production (Fischer et al. 2014). Separation and land sparing aim for setting land aside for conservation, while land outside these areas is used intensively for production. Integration and land sharing aim for spatially less intensive production, leaving less land for separate biodiversity conservation (Green et al. 2005).

Setting land aside as protected areas, or ”sparing land”, has long been seen as a panacea for solving the biodiversity loss dilemma (Hayes and Ostrom 2005). Increasing protected area coverage has therefore been the key conservation target, currently reaching 15% of the global land area under protection, 25% of the EU's land area and 15% of the land area in Finland (Juffe-Bignoli et al. 2014; EEA Statistics 2014). Habitat quality and connectivity are fundamental for species survival (Schooley and Branch 2011). However, protected areas are often too small to contain viable populations, poorly connected and under-representative of many ecoregions (Oldfield et al. 2004; Butchart et al. 2015), and thus do not protect biodiversity in the most effective way possible.

An increase in strictly protected area coverage from the abovementioned numbers may not be economically and socially feasible. It is challenging to establish large, contiguous and well-connected nature reserves in fragmented agricultural and commercial forestry landscapes. An alternative approach, “land sharing”, aiming for the integration of commercial activities and conservation actions, may be more readily applied and provide better results for biodiversity conservation (Green et al. 2005; Fischer et al. 2008; Ekroos et al. 2016).

Despite the scientific debate on the matter (Fischer et al. 2014; Law and Wilson 2015; Ekroos et al. 2016), both strategies are in use in European policy making and implemented by stakeholders working on biodiversity management practices in agricultural (Box 1) and forest (Box 2) environments.

In chapter **I**, I will go more in depth with the integration of land-sparing and -sharing approaches in semi-natural grassland conservation within the framework of EU’s Common Agricultural Policy (Box 1). Sparing semi-natural grassland habitats on farmland has been considered the primary conservation objective because of the drastic decrease in their number during past decades (Stoate et al. 2009; Hodgson et al. 2011; Cousins et al. 2015; Ekroos et al. 2016). Nevertheless, effective semi-natural grassland biodiversity conservation outcomes cannot arguably be achieved by only sparing scattered solitary parcels of land because of the significant effect that the quality of the surrounding farmland has (Söderström et al. 2001; Eycott et al. 2012; Rösch et al. 2013; Slancarova et al. 2013; Janišová et al. 2014). Thus, not only the amount of suitable habitat, but also environmental heterogeneity, i.e. the variety and extent of habitats in the landscape, matters in farmland biodiversity conservation (Öster et al. 2007; de Bello et al. 2010).

Box 1. Voluntary biodiversity management of semi-natural grasslands in the context of European Union's Common Agricultural Policy programme

Agricultural intensification is the main reason for the decline of current biodiversity in agricultural environments. To halt this decline the European Union introduced Agri-Environment Schemes (AES) already in the 1990s as part of the Common Agricultural Policy (CAP). CAP is implemented in seven-year programme periods. Finland joined the EU in 1995 and has participated in the programme periods from 2000–2006, 2007–2013, and 2014–2020. Emphases on biodiversity conservation activities are restructured for each programme period.

Each member state is obliged to participate in AES, but can implement them according to country- and region-specific needs. Farmers may choose from a pool of AES activities on how to participate in environmental management actions. However, farmer income often depends entirely on CAP payments and e.g. geographical or climatic conditions limit farmer's freedom of choice in the AES activities.

AES provide payments to farmers who put environmentally friendly farming management actions into practice. Over 90% of Finnish farmers participate in AES, to some degree at least (Grönroos and Hietala-Koivu 2007). Many of the biodiversity-rich habitats in agricultural environments, such as valuable semi-natural grasslands, require active and continuous management actions to prevent them from overgrowing. Even so, farmers have no obligation to manage these most threathened habitats but can choose between other biodiversity friendly farming practises.

AES are different from typical protected area schemes, i.e. from "land sparing" -type approaches, in that biodiversity actions are also targeted to small patches of land where valuable species may not even occur, thus applying a "land sharing" -type of approach enhancing biodiversity more equally in the fragmented landscape. These measures are explained in more detail in chapter I.

AES are the single most significant budgetary means in biodiversity conservation implementation used in Europe, reaching 22.6 billion euros during the latest full programme period of 2007–2013 (annually ca. 3.2 billion euros), Finland's share of which was approximately 600 million euros (annually approximately 85.7 million euros) (EU 2011; Pe'er et al. 2014; Batáry et al. 2015). The CAP overall budget for the period 2014–2020 will, for the first time in its history, be reduced by 3% (Niemi et al. 2014).

Chapter **I** of this thesis builds on this framework in one case study region in Finland, and further develops the possibilities of integrating the voluntary AES means during the CAP programme period 2007–2013 into spatial prioritization in Finland, to more effectively meet the European level of biodiversity conservation targets.

Chapter **II** will go more in depth with the integration of land-sparing strategy and voluntary conservation of the Finnish Forest Biodiversity Programme METSO (Box 2). As forestland in Finland is mainly under commercial use, landowners make influential decisions on whether their forests are under intensive commercial use, less intensive land-sharing type of use or separate land-sparing protection. Land-sparing or -sharing strategies are not independent factors in biodiversity conservation, but strongly linked to the socio-political reality, which I will elaborate in the following sections.

Box 2. Voluntary forest biodiversity conservation in the context of the Finnish Forest Biodiversity Programme METSO

The forest conservation programme METSO was initiated by a government resolution in Finland (Government of Finland 2008) for the period from 2008 to 2025. It aims to halt the ongoing biodiversity decline in southern Finland's forest ecosystems. The overall target is to establish 96 000 hectares of new protected areas, considered as "sparing land", on private forestland during the project period. Nearly 43 000 ha of this target had been realized by the end of 2015. In addition to establishing new protected areas, METSO also aims to employ the nature management and preservation of valuable forest biotopes, seen as "sharing land" in ca. 100 000 ha of commercially managed forest.

The METSO programme is based entirely on a landowner's voluntary will to participate. Whenever a landowner offers forest areas to the programme, they go through an evaluation process on a set of ecological criteria prior to acceptance. If accepted, landowners receive full financial compensation for the economic loss when refraining from commercial forest management.

The programme has turned out to be so attractive with private landowners that the annual budget reserved by the Finnish government has been insufficient. In addition, since 2015 the annual budget for the programme has been cut back by nearly 50%, from approximately 38 million euros in 2015 to 20 million euros in 2016.

For the reasons mentioned above, the need for prioritization of valuable sites for conservation has emerged in recent years. A project called *Zonation Decision-Support for METSO* (MetZo) ran in 2010–2014, which aimed to identify spatial conservation priorities in state-owned forest and peatland ecosystems. In addition, it enhanced capacity building and knowledge transfer between partnering public organizations.

Chapter **II** in this thesis builds on this framework and further develops the possibilities of integrating private landowner attitudes to spatial prioritization to more effectively target limited financial resources ecologically and socially.

1.3 Spatial conservation prioritization as a tool for multi-objective and larger-scale biodiversity conservation

Systematic conservation planning has emerged from the need for a more quantitative and systematic approach to conservation (Margules and Pressey 2000). Spatial conservation prioritization, a research branch within this framework, attempts to optimize the protected area network (Moilanen et al. 2009b). It provides a quantitative approach for assessing broader-scale land sparing or sharing -type of environmental planning problems such as the ones provided in this thesis.

The essence of spatial conservation prioritization involves a series of spatial choices made in a given landscape. It is based on complementarity analyses with numerical algorithms and spatial data on relevant biodiversity attributes such as species distributions or habitat conditions (Ferrier and Wintle 2009). As protected areas alone cannot stop declining biodiversity trends, conservation actions must also target areas between protected areas (Hanski 2011), and this land-sharing approach is possible to integrate in the optimization process (as in chapter **I**).

In addition to valuing areas only by their biological features, it is possible to value costs or other more qualitative data, such as expert knowledge or stakeholder perceptions (as in chapter **II**). Conservation prioritization is thus inherently a multi-objective problem (Pressey et al. 2007; Nelson et al. 2009) and it can often result in trade-offs between various targets. Spatial conservation prioritization is able to provide alternative solutions for consideration in the planning process (Margules and Pressey 2000; Wu et al. 2011).

Specific conservation strategies are needed for the prioritization of fragmented or modified environments. It can be challenging because the environment consists of heterogeneous landscapes in space and time, and the functions of species vary accordingly (Margules and Pressey 2000). Effective management of natural resources and biodiversity conservation require understanding scale dependency (Tscharntke et al. 2012) because various spatial scales can have differing effects on biodiversity, even for the same taxa (Gabriel et al. 2010).

Connectivity is another central concept that is often included in spatial conservation prioritization. Habitat connectivity is an important feature of a landscape because it affects the ability of species to disperse between suitable habitats and enhances the viability of (meta)populations. Decreasing habitat connectivity hampers the colonization of empty habitat patches because it decreases the frequency of movements between suitable habitat patches, especially into distant isolated patches (Hanski 1998). Connectivity is an integral part of the interplay between habitat area, quality and their spatial aggregation. Habitat quantity and quality coincidentally increase connectivity (Hodgson et al. 2009), thus the integration of all these factors in spatial prioritization is of vital importance.

Current AES measures (Box 1) do not account for habitat connectivity because financial aid is allocated at the farm-level and is based on the voluntary participation of farmers (Arponen et al.

2013). This is an important shortcoming of the programme, as habitat fragmentation not only decreases connectivity, but also weakens landscape heterogeneity by reducing the number and size of habitats and by increasing the unfavourable spatial arrangement of habitats (Brückmann et al. 2010; Perović et al. 2015). Similarly, the METSO programme (Box 2) has not, to date, accounted for the connectivity of areas offered for conservation by private landowners.

Landscape-level spatial conservation prioritization forms the conceptual background for this thesis, which aims to find solutions to the problems facing multi-objective conservation planning.

1.4 Integration of policy-based conservation strategies into biodiversity conservation planning

Approximately 60% of the European Economic Area's forests are privately owned (MCPFE 2007), whereas farmers have complete ownership over farming activities on their farmland. Protecting biodiversity on private land is therefore critical for effective biodiversity conservation targeting (Knight 1999). This leaves a remarkable potential for broadening biodiversity conservation activities involving private landowners (Mayer and Tikka 2006; Selinske et al. 2015).

Complex conservation issues strive for integrated analytical approaches and conceptual frameworks emphasizing knowledge synthesis, stakeholder involvement, along with social and ecological system sustainability (Smith et al. 2009; Knight et al. 2010). Conservation outcomes can be improved by engaging landowners and stakeholders in the planning process because they increase social acceptance while retaining ecological grounds (Whitehead et al. 2014). Landowners tend to oppose centrally designed "top-down" conservation plans, but voluntary contracting with a "bottom-up" approach can increase acceptance, because it respects landowner autonomy over land-use decisions (Paloniemi and Tikka 2008; Paloniemi and Vainio 2011).

However, a voluntary approach may not efficiently allocate conservation resources at a landscape scale (Doremus 2003). While ecological spatial prioritizations have become frequent, s ocial values have rarely been integrated in spatial prioritization analyses (Whitehead et al. 2014). Integration of spatially explicit social values and ecological data into conservation prioritization enables the identification of socially feasible conservation actions that protect nearly equal amounts of ecological values (Whitehead et al. 2014).

Thus, voluntary conservation should be integrated into systematic conservation planning (Grantham et al. 2010; Knight et al. 2011), despite it involving particular planning and prioritization challenges. Landowner attitudes towards conservation are hard to collect and evaluate, and site availability for conservation may remain uncertain. This creates challenges for carrying out a conservation prioritization analysis.

In this thesis two types of policy-based conservation strategies are integrated into spatial conservation prioritization: the Agri-Environment Schemes of EU's

Common Agricultural Policy (Box 1) and the Finnish Forest Biodiversity Programme METSO (Box 2). These biodiversity conservation programmes are different by nature, as farmers depend economically greatly on CAP whereas the METSO programme more often provides additional income to those forest owners who earn their living outside forestry or are retired. In addition, payment principles of these programmes vary. Financial compensation for forests is based solely on biodiversity value whereas AES payments can also be granted to habitats that do not contain high biodiversity values as such but support less intensive agricultural practises. Due to historical reasons quite a few farmers in Finland are also forest owners. Therefore, they are able to profit from both programmes.

Both programmes have several common principles even though they are applied in different types of environments, as both are founded on (i) certain voluntariness of landowner participation instead of direct top-down orders from authorities. Both programmes provide (ii) financial incentives for landowners who adopt environmentally friendly agricultural or forest practices or leave land under protection, and both implement (iii) land-sparing and land-sharing conservation strategies. But to date, neither have profited from spatial prioritization approaches, where both ecological and social realms are simultaneously considered to mediate the acceptability of conservation implementation.

1.5 Aim of the thesis

In this thesis, I present two chapters that address the challenge of multi-objective landscape-level conservation planning in agricultural and forest environments. By using the spatial conservation planning software Zonation, optimization approaches are developed that simultaneously consider the existing ecological and socio-political realities of the study areas.

Specifically, the main objectives in this thesis are:

1. To integrate land-sparing and land-sharing strategies in farmland conservation prioritization to demonstrate joint co-benefits and emerging trade-offs for biodiversity (**I**).

2. To demonstrate how spatial priorities change when various conservation targets are accounted for (**I** and **II**).

3. To demonstrate the integration of social and ecological data into conservation prioritization. Existing Common Agricultural Policy targets (**I**) and landowner perceptions (**II**) are included in prioritization analyses to increase the efficiency of conservation actions and to improve their acceptance.

2. MATERIALS AND METHODS

2.1 Study areas

This thesis includes case studies from Finland, the northernmost country of the EU (Figure 1). Its main land cover type is woodland. Forestry is the primary land-use form in Finland, contrary to most other EU countries, where agriculture is the most widely spread form. The study areas are concentrated in the southern part of the country, where boreal and hemi-boreal forests (80% of the land surface area in Eastern and 65% in Western Finland) and cropland (5% in Eastern and 25% in Western Finland) are the two most dominant land cover types (EEA 2012; Official Statistics of Finland 2015).

The study area of Chapter I is inhabited by 700 000 people, which is 13% of Finland's total population. Wheat and barley are the most commonly cultivated crops in Southwest Finland (Official Statistics of Finland 2015). Scots Pine (48%) and Norway Spruce (34%) dominate forestland with a minor proportion of other deciduous trees (Finnish Forest Centre 2016a). The climate is coastal, and winters are therefore warmer than elsewhere in the country, which has made the region more favourable for agriculture in northern climatic conditions. Clay soil makes the area more fertile for crop production than elsewhere in Finland. Topography is rather flat because the area was the bottom of the sea during the Ice Age.

The study area in Chapter II in Eastern Finland is sparsely inhabited by 166 500 people, or 3% of Finland's total population. Scots Pine (65%) and Norway Spruce (22%) dominate forestland with a minor proportion of other deciduous trees. Eight per cent of Finland's tree reserves are located in Eastern Finland, which makes the area an important commercial forest producer (Finnish Forest Centre 2016b).

Conservation prioritization analyses of agricultural (**I**) and forest (**II**) environments were conducted in the Southwest Finland (Figure 1). Social study areas (Figure 1) for the Finnish Forest Biodiversity Programme METSO (**II**) were chosen to represent regional variation across southern Finland.

2.2 Data

In this thesis, I combined ecological and socio-political data in spatial conservation prioritization. A summary of the data is presented in Table 1. The details of data generation and the methods applied are provided in the respective chapters (**I** and **II**).

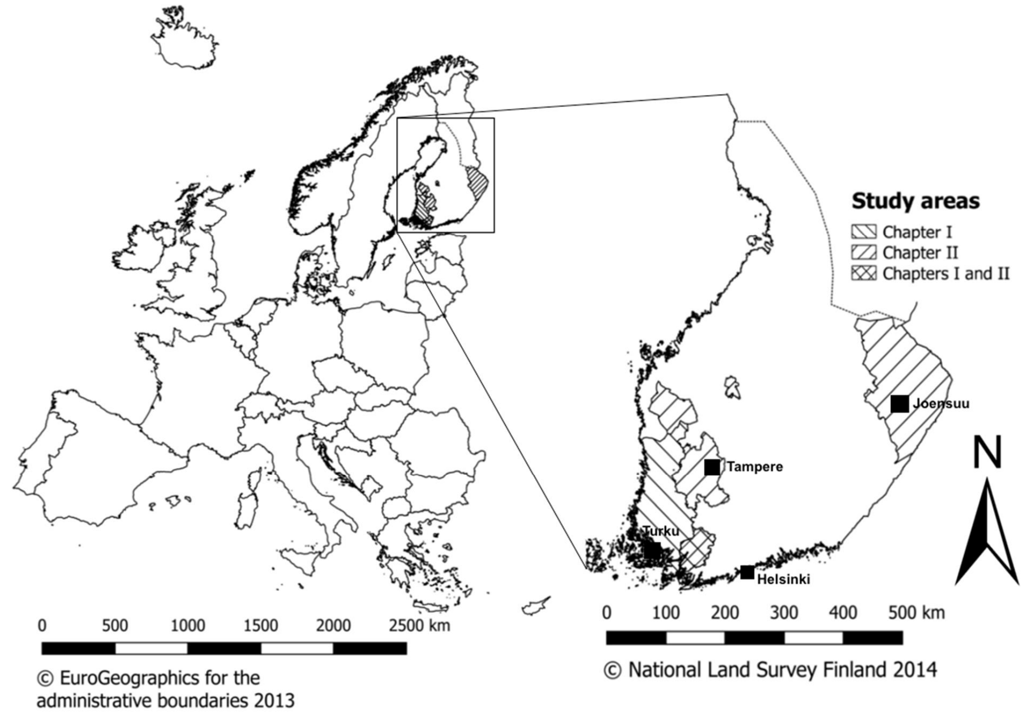

Figure 1. The study areas of the thesis chapters with regional centre cities and the capital are presented with slash lines. The dashed line indicates the northern border of the Finnish Forest Biodiversity Programme METSO. EU's Agri-Environment Scheme programme is applied throughout the country.

Table 1. Data summary of GIS and other data used in Chapters I and II of the thesis.

Chapter I

Data package and features	Format	Source and year
Finnish National Land Survey open semi-natural grasslands	raster	Finnish Environment Institute 2001
SLICES Land Cover open grasslands water area borders	vector	Statistics Finland 2005
Integrated Administration and Control System (IACS) Finnish database		Statistical Services of Ministry of Agriculture and Forestry 2007
field parcels organic farming field parcels agricultural production line permanent pastures buffer zone contract 5–20 years biodiversity contract 5–20 years	vector	
Corine Land Cover (CLC) forest area borders	vector	EU Copernicus Services 2006

Chapter II

Data package and features	Format	Source and year
Finnish National Land Survey wooded semi-natural grasslands	raster	Finnish Environment Institute 2001
Multi-source national forest inventory of Finland (MS-NFI) 20 feature layers in: four tree species groups: pine, spruce, birch, other broadleave trees five habitat types: Dry upland forest site, Vaccinium site, Fresh mineral soil forest site, Upland forests with grass-herb vegetation, Herb-rich forest	raster	Natural Resources Institute 2006
Landowner survey paper questionnaire	transformed to raster	Finnish Environment Institute 2014
Workshop discussions	recorded tape > transcribed	Finnish Environment Institute 2014

2.2.1 Ecological data for spatial prioritization

We used ecological data from two different land-use categories: forest and agricultural environments.

In chapter **I** we acquired data for spatial prioritization in agricultural environments. Local habitat quality of semi-natural grasslands was acquired from the Finnish national land survey (Vainio et al. 2001) and SLICES land cover data base (National Land Survey of Finland 2005). Data acquisition for Chapter **I** was performed during the CAP programme period 2007–2013. We also acquired data on landscape heterogeneity elements in the surroundings of these biodiversity-rich semi-natural grassland habitats. This data was based on Finnish Integrated Administration and Control System (IACS 2007) data statistics and consisted of information concerning the production line and the parcels entitled to agri-environment payments according to AES. These measures were semi-natural grasslands under management contract, permanent pastures, buffer zones, organically cultivated fields, and biodiversity and landscape management contract fields. CAP programme period 2014-2020 restructures these biodiversity measures differently.

Forest data for chapter **II** were derived from multi-national forest inventory (**II**, Annex C). We additionally used wooded semi-natural grassland data drawn from the Finnish national survey (Vainio et al. 2001) to account for all biodiversity-rich wooded habitats in the prioritization.

2.2.2 Socio-political data

The Agri-Environment Schemes, i.e. EU's policy instrument, set the socio-ecological frames for our data in chapter **I** (Strohbach et al. 2015). Our conservation prioritization included most of the AES biodiversity elements that are financially compensated for farmers. These data included land-use information for each field parcel in the landscape and were drawn from the Finnish IACS data statistics.

Social data in chapter **II** were based on a landowner survey and dialogue workshops. First, a questionnaire was mailed to private forest owners to acquire their perceptions about conservation using a set of statements related to the principles and means of safeguarding biodiversity (**II**, Annex A). These landowner perceptions were integrated into spatial prioritization. Second, we organized nine workshop discussions to explore other stakeholders' (local land owners, forestry and conservation authorities, forestry professionals, researchers, and nature enthusiasts) perceptions on how the various information sources could support conservation targeting in practice.

2.3 Methods

2.3.1 Spatial conservation prioritization using Zonation

We chose the Zonation conservation software tool to simultaneously include all conservation targets in the analyses. In addition to Zonation, several different approaches and software packages have been developed for conservation prioritization. These include MARXAN (Watts et al. 2009), C-Plan (Pressey et al. 2009) and ConsNet (Sarkar et al. 2006). Zonation (Moilanen et al. 2009a; Moilanen et al. 2014) differs from the other approaches in that it primarily produces a priority ranking assuming that "protecting everything would be best for conservation" rather than "satisfying targets with minimum cost" -type solutions. Moilanen et al. (2011) further defines that "Zonation is also applicable to very large data sets (landscapes of up to tens of millions of grid cells with data), being able to evaluate species-specific connectivity considerations at large extents using fine-resolution data, making it suitable to develop conservation priorities that are ecologically relevant and also appropriate to the scale of land management decisions."

After having set conservation objectives, spatial prioritization includes the following phases: (i) data pre-processing, (ii) spatial prioritization analyses and (iii) interpretation of results for conservation action (Lehtomäki and Moilanen 2013).

The pre-processing stage was mainly produced with GIS geoprocessing tools (this thesis used ArcGIS, ESRI® ArcMAP™ 10.0) because Zonation can accept input data only in raster format harmonized with same spatial resolution. We used habitats as our ecological data, which required the harmonization of agricultural habitat data (**I**) and forest and wooded semi-natural grassland habitat data (**II**) explained in detail in the respective chapters. Our social data for chapter **II** were transferred into spatial format by retrieving coordinates for the land parcels of various landowners from the national land register.

Data pre-processing also includes conservation priority settings for each feature layer. This way Zonation allows users to determine the relative importance of each feature layer by setting weights, which influences the emerging prioritization solutions (Moilanen et al. 2011a). Each feature was given a relative weight according to its biodiversity value. We used the Additive benefit function -variant of Zonation, which takes into account all weighted features in a raster cell instead of only the highest feature value, i.e. all biodiversity features in a given cell are summed. This function variant is considered most appropriate when the features are essentially surrogates for species such as the habitat types in our study.

In addition to feature weights for the prioritized grassland (**I**) and forest (**II**) features, we gave weights to the landscape heterogeneity (**I**) and landowner perceptions (**II**) features. These data were not ranked in the prioritization, but used indirectly to drive the priorities towards more heterogeneous landscapes (**I**) or more positive landowners (**II**). An exploratory factor analysis was run on the statements to integrate landowner perceptions into spatial prioritization. Factor scores were transformed into weights to indicate the landowner's attitude toward conservation (**II**, Annex C).

We accounted for connectivity measures in all the prioritization analyses. The distance between similar habitats indicates the mean of the negative exponent dispersal kernel used in the "Distribution smoothing" in Zonation (Moilanen et al. 2014). The smoothing spreads out the value of the focal cell into its surroundings, so that whenever many cells occur nearby, the overlapping kernels ensure that well-connected sites receive a higher value in the prioritization.

Two sets of spatial conservation prioritization analyses with Zonation v4.0 were conducted in this thesis; one in agricultural environments with four analysis variants (**I**) and one in forest environments with three analysis variants (**II**). Analysis variants enabled us to detect the emerging co-benefits or trade-offs that various conservation targets may cause. Hierarchical priority rankings produced in the analysis were customized into selected top fractions for cartographical use and charts in ArcGIS and R v3.2.1 (R Development Core Team 2008). These categorizations visualized the differences between each analysis variant.

2.3.2 Social data analyses

Chapter **II** included two types of social data analyses. The landowner survey (n=541, response rate 23%) was built on statements concerning various viewpoints on conservation. An exploratory factor analysis (Gorsuch 1988) was run on the statements to reveal and group various landowner attitudes.

We organized nine discussions (n=59) in three workshops to explore stakeholder perceptions on how the various information sources could support conservation that targets landscape-level ecological goals. To elicit debate, the discussions were structured around statements concerning the implementation of environmental policies (Mickwitz 2003), including the Forest Biodiversity Programme and the roles of various actors in landscape-level conservation (**II**, Annex D). The discussions were recorded and transcribed. The contents of the discussions were analysed using NVivo software (Berg 2011; Bazeley and Jackson 2013), exploring how stakeholders discussed (i) the possibilities to improve conservation outcomes through prioritization analyses and (ii) possibilities to integrate knowledge on social constraints into conservation planning in their practices.

3. RESULTS AND DISCUSSION

Biodiversity conservation is not one problem, but a complex set of many problems (Game et al. 2014). This thesis focused on finding solutions that integrate landscape-level biodiversity conservation, natural resource management and policy-based conservation strategies influencing the implementation of the two aforementioned. The interplay between various factors acting at different levels made it challenging to find one-solution-fits-all type answers.

Here, I present the most relevant findings of this thesis and discuss how these findings relate to the thesis objectives. I will first consider how habitat and surrounding matrix quality indices can be used in conservation prioritization and what co-benefits and trade-offs multi-objective conservation targets can entail. As conservation competes with other land uses in the real world, I then consider how socio-political factors influenced our conservation prioritization outcomes.

We were able to demonstrate the crucial role of understanding landscape-level dynamics to the success of conservation scenarios when we integrated various conservation targets into the spatial prioritization process.

3.1 Land-sparing and land-sharing approaches can produce co-benefits for biodiversity conservation

Current voluntary biodiversity conservation programmes, AES (Box 1) and METSO (Box 2), utilize both land-sparing and land-sharing strategies to present landowners with incentives for biodiversity conservation. In chapter **I** we demonstrated how these two strategies could be integrated in spatial conservation prioritization particularly in agricultural environments.

Because of the drastic decrease in the amount of semi-natural grassland habitats during past decades, the sparing of these habitats has been seen as the primary conservation objective (Prevedello and Vieira 2010; Hodgson et al. 2011; Ekroos et al. 2016). In our conservation prioritization we emphasized the importance of sparing high-quality semi-natural grassland habitats over habitat quantity because other grassland habitats included in our study landscape were unlikely to provide additional (Prevedello and Vieira 2010) high-quality habitats for threatened and declining grassland species. This viewpoint is supported by Ekroos et al. (2016), who emphasize that traditional semi-natural grasslands usually have a long management history that has generated distinctive animal and plant species compositions (and, for example, associated seed banks) that cannot easily be substituted by other younger grasslands.

However, the role of grassland sites with lower local quality should not be downplayed. This is because these sites may support farmland biodiversity by enhancing connectivity and the probability of dispersal between high-quality sites. They may also provide potential sites for restoration, especially when located close to high-quality grassland sites. More generally, as illustrated by our analysis in chapter **I**, inclusion of grassland sites with lower local quality in the broader-scale prioritization can importantly enhance the consideration of multi-objective landscape-level ecological processes.

In addition to lower quality grassland sites used as a land-sparing conservation strategy, we found that other biodiversity-rich habitats contributing to land sharing had an effect in conservation prioritization (Figure 2, chapter 3.2). The land-sharing approach generates a more heterogeneous landscape, where many habitat generalists may profit from secondary patches as complementary resources and movement facilitators (Tscharntke et al. 2012). The type of matrix in the surrounding landscape has been proven important for biodiversity conservation, while override patch size and isolation of truly valuable habitats has not (Prevedello and Vieira 2010).

In our conservation prioritization, areas with higher compositional (land cover -type) heterogeneity also maintained higher connectivity (Table 2, chapter 3.3). This points to increasing crop production intensity having agglomerating biodiversity degradation effects. According to our prioritization analysis, relatively high configurational (field margin -based) heterogeneity was sometimes preserved, even in otherwise homogeneous and intensively farmed areas in the form of dense field margin networks. The coincidence of well-connected grassland habitats and compositional heterogeneity in our conservation prioritization could benefit the directed land-sparing approach. This is in line with the results of Ekroos et al. (2016), which indicated that devoting specific areas of non-crop habitats to conservation outside intensive crop production could lead to more effective biodiversity conservation.

Our conservation prioritization indicates that both land-sparing and land-sharing conservation strategies are important in the implementation of biodiversity management, which is supported by the current AES programme (Box 1), especially in multi-functional landscapes such as agricultural environments. Furthermore, conservation prioritization can be used to identify the co-benefits of landscapes, which profit from land-sparing or land-sharing types of conservation approaches.

3.2 Multi-objective spatial prioritization supports biodiversity conservation targeting, but can entail trade-offs

Conservation prioritization is inherently a multi-objective problem (Pressey et al. 2007; Nelson et al. 2009) and can often result in trade-offs between various targets, where spatial conservation prioritization is able to provide alternative solutions for consideration in the planning process (Margules and Pressey 2000; Wu et al. 2011). We also identified trade-offs concerning our multi-objective conservation scenarios. In chapter **I** we investigated the trade-offs between landscape heterogeneity and connectivity in the conservation prioritization of semi-natural grasslands (Figure 2) and in chapter **II** the trade-offs between landowner perceptions and valuable forest habitats in the conservation prioritization of forest environments (Figure 3). Overall, in agricultural environments landscape heterogeneity did not result in trade-offs with semi-natural grassland habitat quality (panel B in Figure 2). However, when connectivity was integrated with landscape heterogeneity in conservation prioritization the trade-off effect was pronounced (panel D in Figure 2). Furthermore, we found that when landscape heterogeneity was divided into compositional (land cover -type) and configurational (field margin -based) heterogeneity, they formed landscape patterns in agricultural environments (see the following section 3.3).

We were able to show trade-offs of isolated high-quality patches in a less heterogeneous agricultural landscape, indicating that sparing habitat quantity and quality alone does not lead to optimal conservation outcomes. However, it should be noted that even small habitat fragments can maintain overall biodiversity when their spatial arrangement is favourable, i.e. when they are well-connected (Tscharntke et al. 2002; Tscharntke et al. 2012). The most effective conservation strategy may lie, depending on each landscape context, between the combination of maintaining existing, high-quality habitat fragments and biodiversity-rich non-crop habitats (Baum et al. 2004; Rösch et al. 2013).

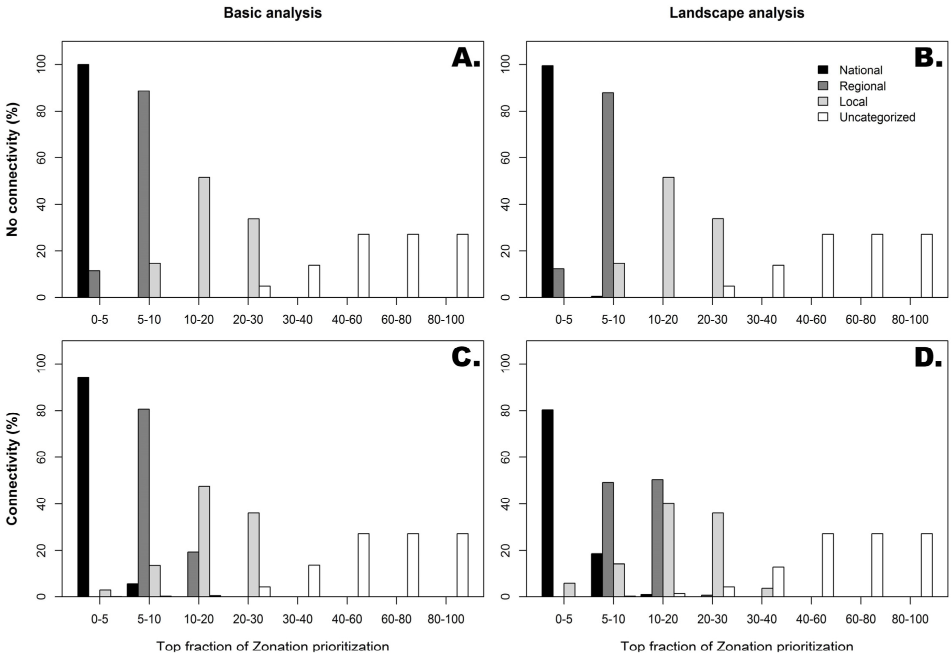

Figure 2. Division of grassland data in the Zonation prioritization ranking in chapter **I** into different top fractions in ”Basic” and ”Landscape” analyses with and without connectivity. The x-axis shows how the prioritized grassland data fall into different top fractions and the y-axis shows the percentage of each grassland category left in the different top fractions, e.g., in panel D the top 5% fraction of cells contains 80% of all nationally valuable semi-natural grasslands. Changes in the top fraction of different analysis variants illustrate the trade-offs for local habitat quality. The greatest loss of most valuable semi-natural grasslands from the top priority fraction can be found when both landscape heterogeneity and connectivity are integrated in landscape-level prioritization (D compared to A). Landscape heterogeneity alone does not result in a trade-off with local habitat quality (B compared to A). Connectivity alone results in modest trade-offs with local habitat quality (C compared to A).

We found that ecologically optimal conservation prioritization (*Ecologically optimized*) had to be compromised in forest environments when landowner perceptions (*Integrated*) were integrated in conservation prioritization (Figure 3). Additionally, the extent of landowner attitudes stressed the trade-off effect. The loss of conservation value due to predicted non-participation (negative perceptions) was 2.4% for the top 5% priority network (2.6% for top 10%), compared to the *Ecologically optimized* analysis. When landowner perceptions were accounted for (*Integrated*), the loss was only 1.1% (1% for the top 10%) (Figure 3).

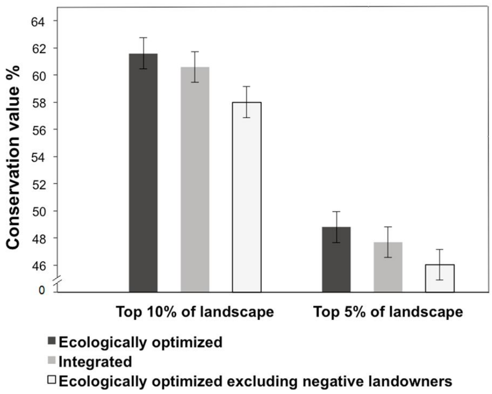

Figure 3. Zonation prioritization results of chapter **II** on forest data illustrate the trade-offs in conservation value between the three analyses. *Ecologically optimized, Integrated* (landowner perception integrated in the analysis) and *Ecologically optimized excluding negative landowners* in top 10% and 5% fractions. The loss of conservation value due to predicted non-participation (negative perceptions) was 2.4% for the top 5% priority network (2.6% for top 10%), compared to the *ecologically optimized* analysis. When landowner perceptions were accounted for (*Integrated*), the loss was only 1.1% (1% for the top 10%). Note that the seemingly large proportions of local quality retained in such small fractions of land area are due to high variation in local quality, from clear-cuts to old-growth forests. and should be interpreted as the poor condition of the region's forests (forestry dominated, few old-growth sites) rather than as our prioritization being successful.

No single conservation strategy is optimal for achieving all conservation goals, especially in regions with competing land-use pressures (Dorning et al. 2015). If fulfilling other targets, this leads to non-optimal solutions for a specific conservation target in question, thus causing inevitably different trade-off levels. Analysing these trade-offs highlights the importance of integrating broader-scale environmental and social contexts to help achieve improved socio-ecological conservation outcomes or create alternative conservation planning approaches.

3.3 Spatial prioritization can reveal landscape patterns

Each landscape is unique in its features, spatial arrangement, size and form. These rudimentary elements influence the ability of species interactions at the landscape level. Conservation prioritization is able to consider these interactions in an optimal way. Prior to the actual conservation prioritization in chapter **I,** we detected certain landscape patterns: valuable semi-natural grasslands and compositional (land cover type -based) landscape heterogeneity had a tendency of spatial clustering (Table 2). This result indicates that valuable, well-connected grasslands tend to cluster, especially in landscapes with abundant landscape elements beneficial to biodiversity.

In our farmland conservation prioritization (**I**), areas with higher compositional heterogeneity also maintained higher connectivity (Table 2). This suggests that increasing crop production intensity has had agglomerating biodiversity degradation effects. According to our prioritization analysis, relatively high configurational heterogeneity was sometimes preserved even in otherwise homogeneous and intensively farmed areas in the form of dense field margin networks. The coincidence of well-connected grassland habitats and compositional heterogeneity in our conservation prioritization could benefit the directed land-sparing approach.

Table 2. Pearson's correlation coefficients of transformed input layers in chapter I produced by Zonation prior to the actual prioritization ranking process. Highest positive correlation (0.92) indicates that better-connected grassland sites are located in landscapes with higher (land cover type -based) compositional heterogeneity than (field margin -based) configurational heterogeneity.

	Correlation coefficients		
	Compositional heterogeneity	Configurational heterogeneity	Connectivity
Compositional heterogeneity	1	0.71*	0.92*
Configurational heterogeneity	0.71*	1	0.62*
Connectivity	0.92*	0.62*	1

*p < 0.01

In chapter **II** we found that landowners with larger sites affected the conservation prioritization more than landowners with smaller sites. Due to connectivity and the uniqueness of the region's feature arrangement, voluntary conservation programmes may create certain landscape patterns due to landowners' willingness to participate. Furthermore, we found that not only landowner perceptions were observed to direct prioritization, but the clustering of voluntary biodiversity actions could be caused by regional forest professionals' perceptions concerning biodiversity, for more details see Salomaa et al. (2016).

3.4 Spatial conservation prioritization potentially improves the effectiveness of voluntary conservation programmes

We developed and demonstrated how CAP targets during the latest full programme period 2007–2013 (**I**) and landowner perceptions (**II**) could be included in the prioritization analyses with the aim of targeting conservation actions efficiently and with higher acceptance.

EU CAP frames biodiversity targets in agricultural environments and closely follows how financial aid is allocated to farmers, but does not direct biodiversity conservation at the landscape level.

The abovementioned clustering of valuable semi-natural grassland habitats and compositional landscape heterogeneity elements could have social relevance in farmland biodiversity conservation. If such clustering turned out to be common in various regions, balancing alternative land uses could be applied (Moilanen et al. 2011a) in agricultural environments while simultaneously working towards social acceptance when potential conflicts were reduced by the separation of alternative land uses.

Voluntary conservation should be integrated into systematic conservation planning (Grantham et al. 2010; Knight et al. 2011), even though it involves particular planning and prioritization challenges. In chapter II we observed that landowner attitudes towards conservation were difficult to collect and evaluate, and even if this collection was successful, site availability for conservation could still remain uncertain. Despite these challenges, our prioritization (**II**) integrating ecological and social information produced an outcome that considerably reduced the loss in conservation value (Figure 3) caused by potential conservation tensions or conflicts. Losses had different levels that depended on landowner qualities. The perceptions of landowners with larger sites affected the prioritization results more than those of landowners with smaller sites, as large sites enable increased conservation value in Zonation due to higher connectivity (Figure 3 in Chapter **II**). This creates challenges for carrying out a conservation prioritization analysis if the area, quality and location of available sites are unreliable.

Ecological, socio-economic and political aspects must all be taken into account when planning effective means for biodiversity conservation (Sutcliffe et al. 2015). If any single aspect is neglected in the process, biodiversity outcomes will automatically have to be compromised. For example, if the political climate is neglected, ecological efforts will be groundless without mutual decisions concerning various actions. If the socio-economic aspect is neglected, voluntary actions will no longer appear appealing to farmers or forest owners, who are the key decision-makers in the process. And finally, if the ecological aspect is neglected, biodiversity targets will not be achieved.

Not only do forests and semi-natural grasslands have remarkable ecological value, but they also have notable cultural and historical value to people and societies (Linnell et al. 2015), which can facilitate the acceptability of biodiversity actions alongside agricultural and forest practices. Voluntary conservation programmes set the framework for conservation targets, but ultimately the adoption of optimal conservation practices in voluntary conservation programmes would depend on decisions made by farmers and landowners on their private land.

3.5 Improving conservation prioritization quality

The conservation prioritization approach may face certain limitations from the perspective of data availability because the resolution of the input data affects the spatial pattern of conservation prioritization. Our data sets had reasonably high resolution: 25x25 metres for agricultural features (**I**) and 60x60 metres for forest features (**II**). However, lack of up-to-date data, which was the case with our semi-natural grassland data, may weaken the reliability of prioritization outcomes. The risk of commission (we prioritize a site based on a feature that does not occur there in reality) or omission (site not prioritized because a feature is mistakenly thought to be absent) errors increase (Rondinini et al. 2006) and reliability problems of prioritization results may occur. To overcome this, the validation of Zonation prioritization results could be performed if appropriate field data existed, but that goes beyond this thesis. Expert opinion is another way of improving data quality (Lehtomäki et al. 2009).

Another challenge that we faced in the prioritization was that we aimed to get all private landowners in the prioritization area to respond to the questionnaire, but found the strategy far too resource-intensive considering the spatial coverage acquired. Even if successful, perceptions are vague and variable by nature. Landownership may change over time, and even the attitude of the same landowner may vary at different times or in different parts of his/her parcels.

The conservation prioritization in this thesis did not cover temporal dimension.. Especially in semi-natural areas that require some kind of management to conserve their biodiversity value, conservation prioritization could account for their future expected state conditional on the difference made by management or the lack of it (Moilanen et al. 2011b).

4. CONCLUDING REMARKS

My thesis produced new information on utilizing multiple landscape heterogeneity elements and landowner perceptions in conservation prioritization to enhance various biodiversity objectives. Conservation prioritization outcomes differed in their responses and generated co-benefits and trade-offs between various conservation targets. Recognition of these potentially contradicting targets is important in the wider conservation planning process.

International treaties and commitments have been made to halt the ongoing biodiversity decline, but results have often remained insufficient (Juffe-Bignoli et al. 2014). Ineffective conservation outcomes can arise from the obstacles between conservation science and practice (Game et al. 2015). Recognized as the knowing-doing gap, knowledge from conservation scientists is not transferred to conservation practitioners (Habel et al. 2013). With our integrative approaches and participatory methods that involved stakeholders, we were able to contribute to this recognized shortcoming.

Based on my results, I have identified three key principles toward a more effective and efficient conservation prioritization process:

1. Current regional coordination of semi-natural grassland biodiversity conservation through the AES programme could be improved by profiting from a landscape-level optimization process such as that performed in Chapter I. This would provide more comprehensive understanding of which landscape features most affect the specific biodiversity objectives in agricultural environments, and identify the most valuable semi-natural grassland habitats for conservation. These measures are independent of CAP programme period emphases, as habitats remain similar for longer periods of time. This approach would help regional environmental authorities adjust the conservation plans to regional conditions and improve the ecological effectiveness without increasing financial inputs.

2. Motivation and attitudes of stakeholders, along with their social dynamics are important components of a conservation planning process. However, gathering landowner perceptions turned out to be challenging in our work. A growing trend of open access data produced by public authorities and electronic services makes it possible to exploit this opportunity in social issues as well. For example, making forest resources data administered by the Finnish Forest Centre publicly available could enable landowners to express their willingness to participate in voluntary biodiversity programmes in the database. This would provide initial information in spatial format nationwide on landowner perceptions towards conservation and improve data coverage in conservation prioritization.

3. Biodiversity conservation is not one problem, but a complex set of many problems. This is why conservation prioritization needs a multi-objective target setting including region-specific ecological, social and political aspects to reach solutions that are both ecologically and financially effective and socially acceptable.

Conservation prioritization is always region-, context- and target-specific, and therefore needs to be adjusted on a case-by-case basis into the conservation planning process. Our prioritization approaches here can be applied in other regions and countries, as similar national forest inventory and agricultural land-use data are also available elsewhere. Stakeholder involvement is not country-specific either, and the Zonation software is publicly available.

Voluntary conservation programmes implement policy-based conservation strategies and require significant public investment. Efforts should therefore be allocated in the best possible way to promote the wise use of conservation funds, for which conservation prioritization can be a suitable tool. However, a large amount of work still remains to be done for better integration of landscape-level targets and social aspects. This thesis contributes its share, as stated in the ten principles of the landscape approach in the UN's Convention of Biological Diversity (Sayer et al. 2013): Effective conservation planning requires integrative approaches in solving conservation issues and responding to international biodiversity conservation targets and land-use tensions in agricultural and forest environments.

ACKNOWLEDGE-MENTS

I am most grateful to my supervisors Anni Arponen and Mikko Kuussaari for their thorough guidance throughout my thesis. Anni's practical help, technical support and patience in answering my endless questions are worthy of great praise. Mikko's broader views on the work as a whole always helped me carry on in situations that felt like dead ends. I wish to express my gratitude to the entire steering group of my thesis project: Irina Herzon, Terho Hyvönen, Minna Kaljonen and Tomas Roslin. I enjoyed our yearly meetings and the instructive comments I have received from you.

I express my thanks for the project workers of the "Knowledge, communication and targeting of biodiversity" project, which was a unique opportunity for me to see how integrative research can be carried out from scratch. Thank you Anni Arponen, Teppo Hujala, Riikka Paloniemi, Eeva Primmer, Sari Pynnönen, Salla Rantala, Anna Salomaa, the regional environmental officers in southwestern and eastern Finland, and the landowners and other stakeholders in the study areas.

I wish to thank all the people in the Metapopulation Research Centre. The supporting and inspiring atmosphere helped me in many ways to take my first steps in the complex world of research. The Journal Clubs in the Global Change and Conservation Group elaborated my thoughts on how to become a scientist.

Kone Foundation financially supported this study. The "Knowledge, communication and targeting of biodiversity" project (chapter II) was financed by the Ministry of Agriculture and Forestry. The LUOVA Doctoral Programme in Wildlife Biology Research provided many useful courses related to my thesis along with social interaction with other students.

LUOVA's coordinator Anni Tonteri did a wonderful job in helping PhD students with all sorts of matters. I am also thankful for the opportunity to deepen my teaching experience at the university level, and the chance to be the student representative of the LUOVA board in 2013–2015. It really opened up my eyes to how important administrative work is for carrying out successful research and teaching. The Metapopulation Research Centre provided me with office tools and administrative support to carry out this research. Thank you Sami Ojanen, Viia Forsblom, Jenni Lehtinen and Kaisa Torppa for keeping the practical things rolling rapidly and smoothly at all times.

My thesis was also supposed to contain a fieldwork chapter, which remains to be completed at another occasion. Regarding this work, I wish to thank fieldworkers Markus Haveri, Riina Järvelä, Jani Järvi, Marika Kuokkanen, Andrea Maier, Martti Rajamäki, Usko Szeto and Aurora Taira. I am thankful to Risto Heikkinen who significantly helped with the plant field data preparation.

Last, but certainly not least, I wish to express my deepest gratitude to my husband Janne, who has had to bear my project for better or for worse.

Your cutting remarks have never failed to make the point, at least after a moment of reasoning. I also wish to thank you and Cipo for your companionship when wandering out in nature. In addition to our numerous unforgettable nature experiences this always reminded me of how this thesis was meant to make a difference.

REFERENCES

Arponen A, Heikkinen R, Paloniemi R, et al (2013) Improving conservation planning for semi-natural grasslands: Integrating connectivity into agri-environment schemes. Biol Conserv 160:234–241. doi: doi:10.1016/j.biocon.2013.01.018

Auffret AG, Cousins SAO (2011) Past and present management influences the seed bank and seed rain in a rural landscape mosaic. J Appl Ecol 48:1278–1285. doi: 10.1111/j.1365-2664.2011.02019.x

Batáry P, Dicks L V, Kleijn D, Sutherland WJ (2015) The role of agri-environment schemes in conservation and environmental management. Conserv Biol 29:1006–16. doi: 10.1111/cobi.12536

Baum KA, Haynes KJ, Dillemuth FP, Cronin JT (2004) The matrix enhances the effectiveness of corridors and stepping stones. Ecology 85:2671–2676. doi: 10.1890/04-0500

Bazeley P, Jackson K (2013) Qualitative Data Analysis with NVivo., Second edi. SAGE Publications Ltd.

Berg BL (2011) Qualitative research methods for the social sciences., Fourth edi. Allyn and Bacon, Boston, MA

Brückmann S V., Krauss J, Steffan-Dewenter I (2010) Butterfly and plant specialists suffer from reduced connectivity in fragmented landscapes. J Appl Ecol 47:799–809. doi: 10.1111/j.1365-2664.2010.01828.x

Butchart SHM, Clarke M, Smith RJ, et al (2015) Shortfalls and Solutions for Meeting National and Global Conservation Area Targets. Conserv Lett 8:329–337. doi: 10.1111/conl.12158

Cousins SAO, Auffret AG, Lindgren J, Tränk L (2015) Regional-scale land-cover change during the 20th century and its consequences for biodiversity. Ambio 44:17–27. doi: 10.1007/s13280-014-0585-9

de Bello F, Lavorel S, Gerhold P, et al (2010) A biodiversity monitoring framework for practical conservation of grasslands and shrublands. Biol Conserv 143:9–17. doi: 10.1016/j.biocon.2009.04.022

Doremus H (2003) A policy portfolio approach to biodiversity protection on private lands. Environ Sci Policy 6:217–232. doi: 10.1016/S1462-9011(03)00036-4

Dorning MA, Koch J, Shoemaker DA, Meentemeyer RK (2015) Simulating urbanization scenarios reveals tradeoffs between conservation planning strategies. Landsc Urban Plan 136:28–39. doi: 10.1016/j.landurbplan.2014.11.011

EC (2015) The State of Nature in the European Union. COM(2015) 219 final.

EC (2011) Our life insurance, our natural capital: an EU biodiversity strategy to 2020. COM(2011) 244 final. Brussels

EEA (2008) European Environment Agency. Land use. Accessible at http://www.eea.europa.eu/themes/landuse/intro. Copenhagen

EEA (2012) European Environment Agency. Land cover 2006 and changes country analysis. http://www.eea.europa.eu/data-and-maps/figures/land-cover-2006-and-changes#tab-metadata. Accessed 25 Mar 2016

Ekroos J, Ödman AM, Andersson GKS, et al (2016) Sparing Land for Biodiversity at Multiple Spatial Scales. Front Ecol Evol 3:1–11. doi: 10.3389/fevo.2015.00145

EU (2011) Is agri-environment support well designed and managed? European court of auditors special report no. 7/2011. European Commission, Luxembourg, UK.

Eurostat (2012) Land cover and land use, landscape (LUCAS). Accessible at http://ec.europa.eu/eurostat/statistics-explained/index.php/Land_cover,_land_use_and_landscape. http://ec.europa.eu/eurostat/statistics-explained/index.php/Land_cover,_land_use_and_landscape.

Eycott AE, Stewart GB, Buyung-Ali LM, et al (2012) A meta-analysis on the impact of different matrix structures on species movement rates. Landsc Ecol 27:1263–1278. doi: 10.1007/s10980-012-9781-9

Ferrier S, Wintle BA (2009) Quantitative Approaches to Spatial Conservation Prioritization: Matching the Solution to the Need. In: Moilanen A, Wilson KA, Possingham HP (eds) Spatial Conservation Prioritization Quantitative Methods & Computational Tools. Oxford University Press, New York, NY, p 304

Finnish Forest Centre (2016a) Lounais-Suomen metsäohjelma 2016-2020. Regional Forest Programme of Southwest Finland 2016-2020. https://www.metsakeskus.fi/sites/default/files/smk-alueellinen-metsaohjelma-lounais-suomi.pdf.

Finnish Forest Centre (2016b) Pohjois-Karjalan metsäohjelma 2016-2020. Regional Forest Programme of North Carelia 2016-2020. https://www.metsakeskus.fi/sites/default/files/smk-alueellinen-metsaohjelma-pohjois-karjala.pdf.

Fischer J, Abson DJ, Butsic V, et al (2014) Land Sparing Versus Land Sharing: Moving Forward. Conserv Lett 7:149–157. doi: 10.1111/conl.12084

Fischer J, Brosi B, Daily GC, et al (2008) Should agricultural policies encourage land sparing or wildlife-friendly farming? Front Ecol Environ 6:380–385. doi: 10.1890/070019

Gabriel D, Sait SM, Hodgson JA, et al (2010) Scale matters: the impact of organic farming on biodiversity at different spatial scales. Ecol Lett 13:858–69. doi: 10.1111/j.1461-0248.2010.01481.x

Game ET, Meijaard E, Sheil D, McDonald-Madden E (2014) Conservation in a Wicked Complex World; Challenges and Solutions. Conserv Lett 7:271–277. doi: 10.1111/conl.12050

Game ET, Schwartz MW, Knight AT (2015) Policy Relevant Conservation Science. Conserv Lett 8:n/a-n/a. doi: 10.1111/conl.12207

Godfray HCJ, Beddington JR, Crute IR, et al (2010) Food Security: The Challenge of Feeding 9 Billion People. Science (80-) 327:812–818.

Gorsuch RL (1988) Exploratory Factor Analysis. In Nesselroade J.R., Cattell R.B. Handbook of Multivariate Experimental Psychology., 2nd edn. Springer US, Boston, MA

Government of Finland (2008) Valtioneuvoston periaatepäätös Etelä-Suomen metsien monimuotoisuuden toimintaohjelmasta 2008-2016.

Grantham HS, Bode M, McDonald-Madden E, et al (2010) Effective conservation planning requires learning and adaptation. Front Ecol Environ 8:431–437. doi: 10.1890/080151

Green RE, Cornell SJ, Scharlemann JPW, Balmford A (2005) Farming and the fate of wild nature. Science 307:550–5. doi: 10.1126/science.1106049

Grönroos J, Hietala-Koivu R (2007) Analyysi maatalouden ympäristötukijärjsetelmästä 2000-2006. In: Suomen ympäristö 19. https://helda.helsinki.fi/bitstream/handle/10138/38395/SY_19_2007.pdf?sequence=3. Accessed 25 Mar 2016

Habel JC, Gossner MM, Meyer ST, et al (2013) Mind the gaps when using science to address conservation concerns. Biodivers Conserv 22:2413–2427. doi:

10.1007/s10531-013-0536-y

Hanski I (2011) Habitat loss, the dynamics of biodiversity, and a perspective on conservation. Ambio 40:248–55. doi: 10.1007/s13280-011-0147-3

Hanski I (1998) Metapopulation dynamics. Nature 396:41–49. doi: 10.1038/23876

Hayes T, Ostrom E (2005) Conserving the world's forests: Are protected areas the only way. Indiana Law Rev 38:595–617.

Hodgson JA, Moilanen A, Wintle BA, Thomas CD (2011) Habitat area, quality and connectivity: striking the balance for efficient conservation. J Appl Ecol 48:148–152. doi: 10.1111/j.1365-2664.2010.01919.x

Hodgson JA, Thomas CD, Wintle BA, Moilanen A (2009) Climate change, connectivity and conservation decision making: back to basics. J Appl Ecol 46:964–969. doi: 10.1111/j.1365-2664.2009.01695.x

Janišová M, Michalcová D, Bacaro G, Ghisla A (2014) Landscape effects on diversity of semi-natural grasslands. Agric Ecosyst Environ 182:47–58. doi: 10.1016/j.agee.2013.05.022

Juffe-Bignoli D, Burgess ND, Bingham H, et al (2014) Protected Planet Report 2014. Cambridge, UK

Knight AT, Cowling RM, Difford M, Campbell BM (2010) Mapping human and social dimensions of conservation opportunity for the scheduling of conservation action on private land. Conserv Biol 24:1348–58. doi: 10.1111/j.1523-1739.2010.01494.x

Knight AT, Grantham HS, Smith RJ, et al (2011) Land managers' willingness-to-sell defines conservation opportunity for protected area expansion. Biol Conserv 144:2623–2630. doi: 10.1016/j.biocon.2011.07.013

Knight RL (1999) Private Lands: The Neglected Geography. Conserv Biol 13:223–224. doi: 10.1046/j.1523-1739.1999.013002223.x

Kontula T, Raunio A (2009) New method and criteria for national assessments of threatened habitat types. Biodivers Conserv 18:3861–3876. doi: 10.1007/s10531-009-9684-5

Krauss J, Bommarco R, Guardiola M, et al (2010) Habitat fragmentation causes immediate and time-delayed biodiversity loss at different trophic levels. Ecol Lett 13:597–605. doi: 10.1111/j.1461-0248.2010.01457.x

Kuuluvainen T, Aakala T (2011) Natural forest dynamics in boreal Fennoscandia: a review and classification. 45:823–841.

Law EA, Wilson KA (2015) Providing context for the land-sharing and land-sparing debate. Conserv Lett 10.1111/co:n/a-n/a. doi: 10.1111/conl.12168

Lehtomäki J, Moilanen A (2013) Methods and workflow for spatial conservation prioritization using Zonation. Environ Model Softw 47:128–137. doi: 10.1016/j.envsoft.2013.05.001

Lehtomäki J, Tomppo E, Kuokkanen P, et al (2009) Applying spatial conservation prioritization software and high-resolution GIS data to a national-scale study in forest conservation. For Ecol Manage 258:2439–2449.

Linnell JDC, Kaczensky P, Wotschikowsky U, et al (2015) Framing the relationship between people and nature in the context of European conservation. Conserv Biol 29:n/a-n/a. doi: 10.1111/cobi.12534

Margules CR, Pressey RL (2000) Systematic conservation planning. Nature 405:243–253. doi: 10.1038/35012251

Mayer AL, Tikka PM (2006) Biodiversity conservation incentive programs for privately owned forests. Environ Sci Policy 9:614–625. doi:

10.1016/j.envsci.2006.07.004
MCPFE (2007) State of Europe's forests 2007. The MCPFE Report on Sustainable Forest Management in Europe. Warsaw
Mickwitz P (2003) A Framework for Evaluating Environmental Policy Instruments: Context and Key Concepts. Evaluation 9:415–436. doi: 10.1177/1356389003094004
Millenium Ecosystem Assessement (2005) Ecosystems and human well-being: Synthesis. Washington DC.
Moilanen A, Anderson BJ, Eigenbrod F, et al (2011a) Balancing alternative land uses in conservation prioritization. Ecol Appl 21:1419–1426. doi: 10.1890/10-1865.1
Moilanen A, Kujala H, Leathwick JR (2009a) The Zonation framework and software for conservation prioritization. In: Moilanen A, Wilson KA, Possingham HP (eds) Spatial conservation prioritization. Oxford University Press, Oxford, UK, pp 196–210
Moilanen A, Leathwick JR, Quinn JM (2011b) Spatial prioritization of conservation management. Conserv Lett 4:383–393. doi: 10.1111/j.1755-263X.2011.00190.x
Moilanen A, Possingham HP, Wilson KA (2009b) Spatial Conservation Prioritization: past, present and future. In: Moilanen A, Possingham HP, Wilson KA (eds) Spatial conservation prioritization: quantitative methods and computational tools. Oxford University Press, Oxford, UK, pp 260–268
Moilanen A, Pouzols FM, Meller L, et al (2014) Spatial conservation planning methods and sofware Zonation. Version 4. User manual. University of Helsinki
Nelson E, Mendoza G, Regetz J, et al (2009) Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Front Ecol Environ 7:4–11. doi: 10.1890/080023
Niemi J, Liesivaara P, Lehtonen H, et al (2014) EU's Common Agricultural Policy during 2014-2020 and Finnish Agriculture. MTT Reports 130. Juvenes Print - Suomen yliopistopaino Oy.
Official Statistics of Finland (2015) Utilised Agricultural Area [e-publication]. Natural Resources Institute Finland. http://www.stat.fi/til/kaoma/index_en.html. Accessed 25 Mar 2016
Oldfield TE., Smith RJ, Harrop SR, Leader-Williams N (2004) A gap analysis of terrestrial protected areas in England and its implications for conservation policy. Biol Conserv 120:303–309. doi: 10.1016/j.biocon.2004.03.003
Paloniemi R, Tikka PM (2008) Ecological and social aspects of biodiversity conservation on private lands. Environ Sci Policy 11:336–346. doi: 10.1016/j.envsci.2007.11.001
Paloniemi R, Vainio A (2011) Legitimacy and empowerment: combining two conceptual approaches for explaining forest owners' willingness to cooperate in nature conservation. J Integr Environ Sci 8:123–138. doi: 10.1080/1943815X.2011.576682
Pe'er G, Dicks L V, Visconti P, et al (2014) Agriculture policy. EU agricultural reform fails on biodiversity. Science 344:1090–2. doi: 10.1126/science.1253425
Peltola A (2014) Finnish Statistic Yearbook of Forestry 2014. Available; www.metla.fi/julkaisut/metsatilastollinenvsk/. Tammerprint Oy, Tampere
Perović D, Gámez-Virués S, Börschig C, et al (2015) Configurational landscape heterogeneity shapes functional community composition of grassland butterflies. J Appl Ecol 52:505–513. doi: 10.1111/1365-2664.12394

Pressey RL, Cabeza M, Watts ME, et al (2007) Conservation planning in a changing world. Trends Ecol Evol 22:583–592. doi: 10.1016/j.tree.2007.10.001

Pressey RL, Watts ME, Barret TW, Ridges MJ (2009) The C-Plan conservation planning system: origins, applications, and possible futures. In: Moilanen A, Wilson KA, Possingham HP (eds) Spatial conservation prioritization. Oxford University Press, Oxford, UK, pp 211–234

Prevedello JA, Vieira M V. (2010) Does the type of matrix matter? A quantitative review of the evidence. Biodivers Conserv 19:1205–1223. doi: 10.1007/s10531-009-9750-z

R Development Core Team (2008) R: a language and environment for statistical computing. In: Vienna, Austria R Found. Stat. Comput. ISBN 3-900051-07-0. Available online http//www.R-project.org/. http://www.gbif.org/resource/81287. Accessed 2 Sep 2015

Rassi P, Hyvärinen E, Juslén A, Mannerkoski I (2010) Suomen lajien uhanalaisuus – Punainen kirja 2010, The 2010 Red List of Finnish Species.

Rondinini C, Wilson KA, Boitani L, et al (2006) Tradeoffs of different types of species occurrence data for use in systematic conservation planning. Ecol Lett 9:1136–1145. doi: 10.1111/j.1461-0248.2006.00970.x

Rösch V, Tscharntke T, Scherber C, Batáry P (2013) Landscape composition, connectivity and fragment size drive effects of grassland fragmentation on insect communities. J Appl Ecol 50:387–394. doi: 10.1111/1365-2664.12056

Salomaa A, Paloniemi R, Hujala T, et al (2016) The use of knowledge in evidence-informed voluntary conservation of Finnish forests. For Policy Econ 73:90–98. doi: 10.1016/j.forpol.2016.09.004

Sarkar S, Pressey RL, Faith DP, et al (2006) Biodiversity Conservation Planning Tools: Present Status and Challenges for the Future. Annu Rev Environ Resour 31:123–159. doi: 10.1146/annurev.energy.31.042606.085844

Sayer J, Sunderland T, Ghazoul J, et al (2013) Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proc Natl Acad Sci U S A 110:8349–56. doi: 10.1073/pnas.1210595110

Schooley RL, Branch LC (2011) Habitat quality of source patches and connectivity in fragmented landscapes. Biodivers Conserv 20:1611–1623. doi: 10.1007/s10531-011-0049-5

Selinske MJ, Coetzee J, Purnell K, Knight AT (2015) Understanding the Motivations, Satisfaction, and Retention of Landowners in Private Land Conservation Programs. Conserv Lett 8:282–289. doi: 10.1111/conl.12154

Slancarova J, Benes J, Kristynek M, et al (2013) Does the surrounding landscape heterogeneity affect the butterflies of insular grassland reserves? A contrast between composition and configuration. J Insect Conserv 18:1–12. doi: 10.1007/s10841-013-9607-3

Smith RJ, Veríssimo D, Leader-Williams N, et al (2009) Let the locals lead. Nature 462:280–281. doi: 10.1038/462280a

Stoate C, Báldi A, Beja P, et al (2009) Ecological impacts of early 21st century agricultural change in Europe - a review. J Environ Manage 91:22–46. doi: 10.1016/j.jenvman.2009.07.005

Strohbach MW, Kohler ML, Dauber J, Klimek S (2015) High Nature Value farming: From indication to conservation. Ecol Indic 57:557–563. doi: 10.1016/j.ecolind.2015.05.021

Sutcliffe LME, Batáry P, Kormann U, et al (2015) Harnessing the biodiversity value of Central and Eastern European farmland. Divers Distrib 21:722–730. doi: 10.1111/ddi.12288

Söderström B, Svensson B, Vessby K, Glimskär A (2001) Plants, insects and birds in semi-natural pastures in relation to local habitat and landscape factors. Biodivers Conserv 10:1839–1863. doi: 10.1023/A:1013153427422

Tscharntke T, Steffan-Dewenter I, Kruess A, Thies C (2002) Contribution of small habitat fragments to conservation of insect communities of grassland-cropland landscapes. Ecol. Appl. 12:354–363.

Tscharntke T, Tylianakis JM, Rand TA, et al (2012) Landscape moderation of biodiversity patterns and processes - eight hypotheses. Biol Rev Camb Philos Soc 87:661–85. doi: 10.1111/j.1469-185X.2011.00216.x

Vainio M, Kekäläinen H, Alanen A, Pykälä J (2001) Traditional rural biotopes in Finland. Final report of the nationwide inventory. Finnish Environment Institute. Series 527. Vammala

Watts ME, Ball IR, Stewart RS, et al (2009) Marxan with Zones - software for optimal conservation-based land-and sea-use zoning. Environ Model Softw 24:1513–1521. doi: 10.1016/j.envsoft.2009.06.005

Whitehead AL, Kujala H, Ives CD, et al (2014) Integrating Biological and Social Values When Prioritizing Places for Biodiversity Conservation. Conserv Biol 28:992–1003. doi: 10.1111/cobi.12257

Wu X, Murray AT, Xiao N (2011) A multiobjective evolutionary algorithm for optimizing spatial contiguity in reserve network design. Landsc Ecol 26:425–437. doi: 10.1007/s10980-011-9571-9

Öster M, Cousins SAO, Eriksson O (2007) Size and heterogeneity rather than landscape context determine plant species richness in semi-natural grasslands. J Veg Sci 18:859–868. doi: 10.1111/j.1654-1103.2007.tb02602.x

Biodiversity conservation of semi-natural grasslands profits from a multi-objective and broader scale spatial optimization approach

Annika Harlio, Mikko Kuussaari, Risto K. Heikkinen and Anni Arponen

Manuscript submitted, January 2017

Biodiversity conservation of semi-natural grasslands profits from a multi-objective and broader-scale spatial optimization approach

Annika Harlio • Mikko Kuussaari • Risto K. Heikkinen • Anni Arponen

PHL, MA, A. Harlio (Corresponding author) • Dr. A. Arponen
Metapopulation Research Centre
Department of Biosciences
PO Box 65, 00014 University of Helsinki
Finland
email: annika.harlio@helsinki.fi

Dr. M. Kuussaari • Dr. R. K. Heikkinen
Natural Environment Centre
Finnish Environment Institute
P.O. Box 140, FIN-00251
Helsinki, Finland

Abstract

Context. Recent actions to mitigate biodiversity loss in agricultural environments appear insufficient despite the considerable efforts channelled via the European Union's Common Agricultural Policy. One likely reason for this failure is the limited attention paid to regional- and landscape-level ecological characteristics in farmland conservation planning.
Objectives. We demonstrate how to obtain conservation prioritization solutions that simultaneously address three goals, including two landscape-level targets: minimizing local habitat quality loss, maximizing habitat connectivity and incorporating landscape heterogeneity. As these goals may be contradictory, we investigate the potential trade-offs between them.
Methods. We used the Zonation prioritization tool to examine how our three goals could be implemented in the agricultural landscapes of southwest Finland. We used measures of (i) grassland biodiversity value, (ii) connectivity between grasslands and (iii) landscape heterogeneity comprised of (land cover type -based) compositional heterogeneity and (field margin -based) configurational heterogeneity.
Results. The integration of landscape heterogeneity measures and habitat connectivity resulted in certain trade-offs with local habitat quality, the most prominent observation being that landscape heterogeneity co-varied with grassland connectivity. In the two landscape heterogeneity parameters, the inclusion of compositional heterogeneity resulted in more clustered prioritization solutions than configurational heterogeneity, which had a spatially more balanced impact.
Conclusions. Concordance among landscape-scale factors implies high potential for the reconstruction of a functioning network of semi-natural grasslands in areas under intensive agricultural use. Broader-scale multi-objective planning approaches can thus importantly support targeting biodiversity conservation planning and mediating the implementation of Common Agricultural Policy objectives.

Keywords: agri-environment scheme; field margin; landscape heterogeneity; land sharing and sparing; spatial prioritization; trade-off

Introduction

Agricultural intensification and associated landscape homogenization has led to widespread biodiversity loss in agricultural environments during the second half of the 20th century (Stoate et al. 2009; Kleijn et al. 2011). The European Union's Common Agricultural Policy (CAP) has recognized these alarming trends, and thus increasingly supports the implementation of a number of mitigating measures. Most importantly, agri-environment schemes (AES) are used in seven-year programme periods to direct and financially support farmers towards conserving farmland biodiversity and ecosystem services, and to adopt environmentally friendly agricultural practices (Hicks 2010; Hodge et al. 2015). However, monitoring AES effectiveness measures since the early 2000s indicates that only half of these measures have caused positive biodiversity effects (Kleijn et al. 2011; Batáry et al. 2015). AES poorly acknowledges landscape-level effects on biodiversity, which is one apparent reason for this ineffectiveness (Batáry et al. 2011; 2015; Scheper et al. 2013).

Spatial conservation planning in agricultural environments

The establishment of separate conservation areas ("land sparing") in a landscape has been the most common biodiversity conservation action, advocated e.g. by the Convention on Biological Diversity (Juffe-Bignoli et al. 2014). However, it is challenging to establish large contiguous nature reserves in agricultural landscapes, which are often heavily fragmented and dominated by food production. In addition, leaving land aside for protection does not necessarily fulfil conservation effectiveness in agricultural environments, as e.g. semi-natural grassland habitats generally require active management to preserve their biodiversity values. An alternative approach ("land sharing") aiming for the integration of farming practices and conservation actions, may be more readily applied in such landscapes and provide better results for biodiversity conservation (Green et al. 2005; Fischer et al. 2008; Ekroos et al. 2016). Both approaches are needed to promote biodiversity conservation, and the present aim is for them to work synergistically in an optimal way instead of forcing stakeholders into choosing between one or the other approach (Kremen 2015).

During past decades spatial conservation planning (Margules and Pressey 2000; Butsic and Kuemmerle 2015; Teillard et al. 2016) has provided a quantitative approach to assessing land sparing or sharing -type environmental planning problems. The essence of the approach involves a series of spatial choices made in a given landscape, based on analyses with numerical algorithms and using spatial data on relevant biodiversity attributes such as species distributions or habitat conditions (Ferrier and Wintle 2009). Socio-political factors driven by CAP influence farmland biodiversity conservation, and thereby determine the baseline settings for any conservation planning process in agricultural environments (Margules and Pressey 2000). In the following sections we identify the conceptual framework for a conservation prioritization assessment, which is required for the multi-objective and broader-scale biodiversity conservation of agricultural environments.

Land sparing in conservation prioritization

The loss of semi-natural grassland habitats has been drastic during past decades, and land sparing is therefore often considered the primary means for their conservation (Stoate et al. 2009; Hodgson et al. 2011; Cousins et al. 2015; Ekroos et al. 2016). Loss of individual patches from the network may strongly weaken the persistence of species populations as movement between patches becomes more difficult. Therefore, to mitigate the amount of endangered grassland species in Europe (van Swaay et al. 2011) semi-natural grasslands have become target hotspots for biodiversity conservation efforts in European ecosystems (Hicks 2010; de Bello et al. 2010; Auffret and Cousins 2011; Habel et al. 2013) .

A higher proportion of semi-natural habitats in the landscape appears to have a positive effect on, for example, farmland bird (Smith et al. 2010; Batáry et al. 2011) and butterfly diversity (Öckinger and Smith 2006), whereas grazing animals prevent semi-natural grasslands from overgrowth and eutrophication (Pykälä 2000). Such findings are probably the key underlying causes for emphasizing the land-sparing approach in the AES for biodiversity management and restoration practices, and why AES measures mainly consider either individual habitats or species (Kleijn et al. 2006; McKenzie et al. 2013).

Land sharing in conservation prioritization

Land sharing in agricultural landscapes often includes the integration of farming practices with conservation, and as such, results in landscape heterogeneity. Environmental heterogeneity is often considered to pose supportive impacts on biodiversity and may thus effectively mitigate the negative effects of habitat fragmentation in agricultural landscapes (Tscharntke et al. 2005; Rösch et al. 2013). It has also been argued that sparing scattered solitary parcels of land is arguably not the only measure that achieves effective semi-natural grassland biodiversity conservation outcomes, as surrounding farmland quality also has an important effect (Söderström et al. 2001; Eycott et al. 2012; Rösch et al. 2013; Slancarova et al. 2013; Janišová et al. 2014). Thus, not only the amount of suitable habitat but also environmental heterogeneity, i.e. the variety and extent of habitats in the landscape, matters in biodiversity conservation (Öster et al. 2007; de Bello et al. 2010).

Landscape heterogeneity is often divided into compositional and configurational heterogeneity. The former comprises the variability of various habitat types in an area, while the latter refers to the number, size and arrangement of a certain habitat type (Duelli 1997; Fahrig et al. 2011; Perović et al. 2015). For example, various types of landscape heterogeneity at different spatial scales can have differing biodiversity effects on grassland butterflies (Perović et al. 2015).

AES management actions focus on improving local habitat quality, but they also comprise elements that maintain and add to compositional heterogeneity. During the CAP programme periods 2000–2016 and 2007–2013 the AES system compensated farmers for long-term commitments (5 to 20 years), providing support for various types of biodiversity, buffer zones and landscape management contracts that all add up to compositional heterogeneity in agricultural environments. In addition, organic farming is one feature of compositional heterogeneity that provides a potential AES-related action to mitigate biodiversity loss in agricultural environments owing to reduced agricultural intensity (Bengtsson et al. 2005; Winqvist et al. 2012).

Field margins are a significant part of semi-natural areas in modern agricultural landscapes, and play an important role in creating both habitat and species diversity (Marshall and Moonen 2002). They are landscape elements that typically make an important contribution to configurational heterogeneity in agricultural landscapes. The more field margins in a landscape, the more mosaic-like the landscape structure is. Increased field margin edge length can increase diversity, as boundary areas offer specific resources to different species (Duelli 1997; Stoate et al. 2009; Concepción et al. 2012).

Connectivity in conservation prioritization

Habitat connectivity is an important landscape feature because it affects the ability of species to disperse between suitable grassland habitats and enhances (meta)population viability. Decreasing habitat connectivity hampers the colonization of empty habitat patches because it decreases the frequency of the movements between suitable habitat patches, especially into distant isolated patches (Hanski 1998).

Neither current nor past AES measures have accounted for habitat connectivity in Finland, or in any other EU countries to our knowledge, because financial aid is allocated at the farm level and based on the voluntary participation of farmers (Arponen et al. 2013). This is an important shortcoming because habitat fragmentation not only decreases connectivity, but also weakens compositional landscape heterogeneity by reducing the number and size of habitats and increasing unfavourable spatial arrangements of habitats (Brückmann et al. 2010; Perović et al. 2015).

Aim of the conservation prioritization

Our study addresses the growing need to integrate the principles of spatial ecology and landscape context to AES targets, and aims to develop a spatial prioritization process that also accounts for the potentially emerging trade-offs and synergies (Whittingham 2007; Ekroos et al. 2014; Butsic and Kuemmerle 2015).

Because an increase in non-crop habitats is not necessarily economically and socially feasible (Fahrig et al. 2011), we suggest an approach where the spatial arrangement of existing biodiversity-friendly landscape elements supported by AES is included in the conservation prioritization process. We consider these elements according to their contribution to the land-sparing or land-sharing context. This requires a multi-objective conservation planning approach simultaneously considering local habitat quality, connectivity and landscape heterogeneity. The primary goal of our study is to demonstrate how such a threefold interactive target can be integrated with a broader-scale spatial optimization approach.

Methods

We carried out a prioritization analysis using the Zonation software v4.0, which is a framework for spatial conservation prioritization particularly suitable for large grid-based datasets. The Zonation algorithm begins with a complete landscape, and iteratively removes planning units that contribute the least to remaining biodiversity. As a result it produces a complementarity-based hierarchical priority ranking of the units (Moilanen et al. 2005; Moilanen et al. 2014).

Data compilation

As regional authorities at the Centre for Economic Development, Transport and Environment presently allocate AES support, we chose Southwest Finland (18 000 km^2 in size comprising the provinces of Varsinais-Suomi and Satakunta) as our study area, to represent a broader-scale European case study area (Fig. 1). The region is the most intensively cultivated part of Finland, with cultivated land covering nearly 25% (Official Statistics of Finland 2015) of all land area compared to the 5% average (European Environment Agency 2012) in the whole country. Overall, forests are the most dominant land cover type. The region's agricultural activity is dominated by crop production, animal husbandry being only complementary.

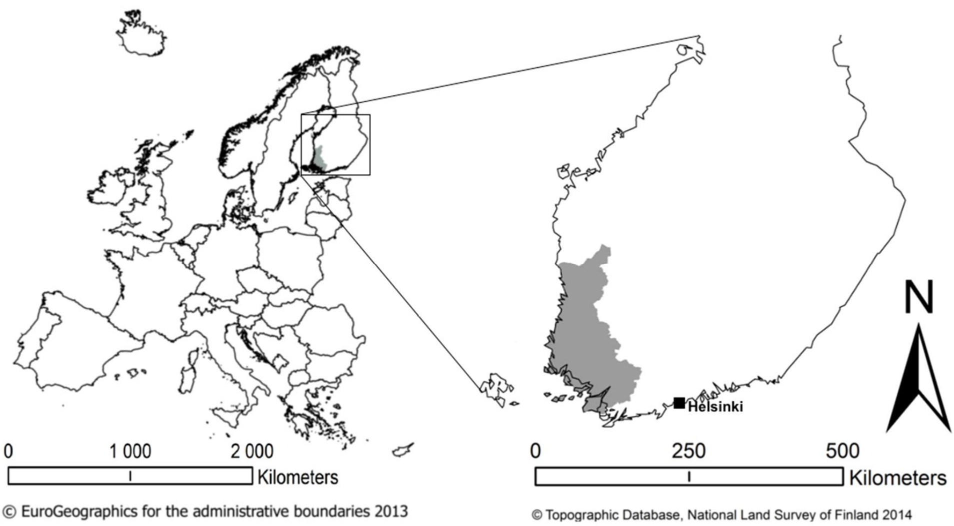

Fig. 1 Study area in Southwest Finland is presented in *grey* on the map. The study area comprises the administrative area of the Centre for Economic Development, Transport and Environment of Southwest Finland.

The data for this study was gathered and analysed in 2013. It therefor reflects on the CAP programme period 2007–2013. Although land sparing and sharing have recently been considered more of a continuum (Fischer et al. 2014; Kremen 2015), for the purposes of our study we assigned the considered land characteristics into these two separate categories only. We used a total of five GIS data sets prepared with ArcGIS (ESRI® ArcMAP™ 10.0) for the analyses. We standardized the coordinate systems and transformed the data into 25 m x 25 m resolution raster layers for all raw data sets described in the following sections.

Land-sparing data

Our land-sparing data contained three types of grassland data, which enabled us to define local habitat quality in each grassland raster cell to indicate local-scale conservation value in the prioritization.

The first data set (1) consisted of traditional open semi-natural grassland biotopes classified into nationally, regionally and locally important according to the Finnish national survey (Vainio et al. 2001). The second data set (2) consisted of all other open grasslands from the SLICES land cover database (Statistics Finland 2005), including locally valuable sites such as long-term set-asides not included in the Finnish national survey (National Land Survey of Finland). Each EU member state is obliged to annually collect its own Integrated Administration and Control System (IACS) database (Lomba et al. 2017), which provides land-use information for AES in spatial format. The third data set (3) consisted of the Finnish IACS data on semi-natural grasslands under management contract and receiving agri-environment payments via AES (Statistical Services, Ministry of Agriculture and Forestry 2007) (Table 1 and Fig. 2, A).

The following procedure was employed to determine in more detail the local value of grasslands in data set two. First, certain sites overlapped in data sets one and two. Such sites were excluded from the second data set and only kept in the first one, either as nationally, regionally or locally important semi-natural grasslands. Second, certain sites overlapped in data sets two and three. Acceptance to AES guarantees a certain degree of conservation value, and therefore the overlapping grassland sites from data set three that were under a management contract were classified in data set two as locally important traditional biotopes (thus equally important as locally important sites in the Finnish national survey in data set one).

Land-sharing data

Our land-sharing data consisted of landscape heterogeneity elements that we partitioned into (land cover type - based) compositional and (field margin -based) configurational heterogeneity.

To assess compositional heterogeneity in the analysis, we compiled various landscape elements that are known to provide habitat variability or resources to grassland species. For this, we further explored the third data set (3) of the Finnish IACS data concerning field parcels (Statistical Services, Ministry of Agriculture and Forestry 2007). These data included the land-use information for each field parcel in the landscape. We used the information concerning the production line and parcels entitled to agri-environment payments according to AES during the programme period 2007–2013. These measures were semi-natural grasslands under a management contract, permanent pastures, buffer zones, organically cultivated fields, and biodiversity and landscape management contract fields (Table 1 and Fig. 2, B).

As a measure of configurational heterogeneity, we included the edge density of field margins into the analyses utilizing the field parcel boundaries of the third data set from the Finnish IACS. Increased edge density refers to more heterogeneous and mosaic-like landscape configuration, as the number, size and arrangement of certain habitat types increase. Edge density was calculated using the kernel density function in ArcGIS. It calculates the density of linear features in the neighbourhood of each output raster cell. We set the sphere of influence to 200 metres, meaning that its value is greatest on the line and diminishes linearly when moving away from it, reaching zero at a 200-m distance from the line. The density at each output raster cell is calculated by adding the values of all the kernel surfaces where they overlay the raster cell centre, and thus areas with more mosaic-like landscape configuration receive higher values.

In addition, we separated different types of field margins because their influence on grassland biodiversity differs. In prioritization, field margins next to forestland (field-forest) are relatively the most important field margin type, as they typically provide habitat for a larger number of grassland species than margins surrounded by cultivated fields (field-field) (Kuussaari et al. 2007; Šálek et al. 2015). Field margins within crop fields (field-field) maintain lower species diversity than field margins next to water elements (field-waterway) (Herzon and Helenius 2008) and serve mainly as corridors (Ma et al. 2013). We used two additional data sets to separate the field-forest margins and field-waterway margins from the field-field margins: (4) the forest data from the Corine Land Cover database (2006) and (5) the water network systems from the SLICES land cover database (National Land Survey of Finland 2005).

After the kernel density calculations we doubled the impact of field-forest margins compared to field-field and field-waterway margins, because of their more significant positive effect to semi-natural grassland biota. In the next step, we normalized the values to the same relative weight with compositional heterogeneity data (Table 1 and Fig. 2, C).

Conservation priority settings for Zonation

Zonation allows users to determine the relative importance of each feature layer by setting weights, which influences the emerging prioritization solutions (Moilanen et al. 2011). We applied the following principles in the feature weighting that was carried out in ArcGIS (Table 1 and Fig. 2): weights for classified semi-natural grassland data (first data set) were assigned according to the conservation value set by the Finnish national survey, and following Arponen et al. (2013). Weights for the second data set, which was uncategorized and included all types of treeless grasslands, were given the lowest value. This was due to limited knowledge of their exact conservation value, but their potential as suitable habitat for common grassland species, along with their locations for future restoration actions.

Weights for the landscape heterogeneity data (third to fifth data sets) were assigned according to their relative importance to grassland biodiversity based on a literature review (e.g. Marshall and Moonen 2002; Batáry et al. 2011; Dengler et al. 2014; Tuck et al. 2014; Gonthier et al. 2014 and references therein). Given the dominance of crop production in our study region, animal husbandry and dairy cattle production were assigned moderate weights to take the more diverse agricultural practices into account during the prioritization process.

Table 1 Raster layers created for the analyses and their relative weights used in Zonation prioritization. Values for configurational heterogeneity feature data were normalized to the same relative weight with compositional heterogeneity feature data.

	BIODIVERSITY FEATURE LAYER	WEIGHT	DATA SET
Prioritized grassland feature data			
	Nationally valuable semi-natural grasslands	40	1
	Regionally valuable semi-natural grasslands	30	1
	Locally valuable semi-natural grasslands	20	1
	Uncategorized grasslands with semi-natural grassland management contract*	20	3
	Uncategorized grasslands	10	2
Landscape heterogeneity feature data			
Compositional			
	Semi-natural grassland management contract*	20	3
	Biodiversity contract 20 years**	16	3
	Biodiversity contract 10 years**	14	3
	Biodiversity contract 5 years**	12	3
	Permanent pastures*	12	3
	Buffer zone contract 20 years*	10	3
	Buffer zone contract 10 years*	8	3
	Animal husbandry farms	8	3
	Buffer zone contract 5 years*	6	3
	Organic farming*	4	3
	Dairy cattle farms	4	3
Configurational			
	Edge density of field-field margins	0–20	3
	Edge density of field-forest margins (values doubled)	0–20	4
	Edge density of field-waterway margins	0–20	5

* These features were financially compensated for farmers through the agri-environment scheme (AES) support system in EU's Common Agricultural Policy during the programme period 2007–2013.
** New contracts were no longer signed during 2007–2013. Existing contracts were transmitted from the previous programme period 2000–2006.

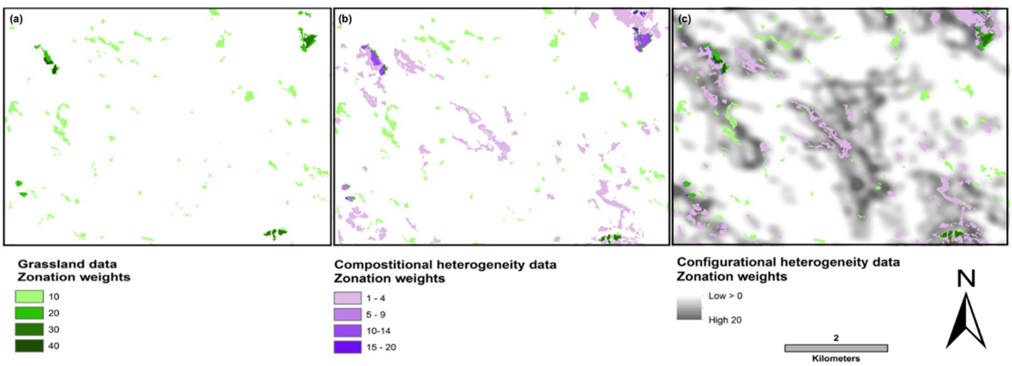

Fig. 2 An example of geographical positioning of grassland data and landscape heterogeneity elements in our data. (a) Grassland habitats are small in size and fragmented around the landscape in our data. (b) Compositional i.e. land cover type -based heterogeneity data in the same landscape. They partially overlap with data in (a) because some grasslands fall under the AES programme. (c) Configurational heterogeneity data i.e. field margin areas in the same landscape. Elements are blurry because the effect of a field margin (sphere of influence set to 200 metres) diminishes smoothly with increasing distance from the margin centre and overlaying margin areas receive higher values (Kernel density effect).

Connectivity settings for Zonation

Both patch quality and habitat connectivity need to be examined while assessing the functionality of a habitat network from the perspective of metapopulation dynamics (Schooley and Branch 2011). Grassland-to-grassland connectivity was set to two km, which is an appropriate scale for many grassland species (Moilanen and Nieminen 2002). This distance indicates the mean of the negative exponent dispersal kernel used in the "Distribution smoothing" in Zonation. Smoothing spreads out the value of the focal cell into its surroundings, i.e. whenever many cells occur nearby, the overlapping kernels ensure that well-connected sites receive a higher value in the prioritization.

In addition to connectivity between grassland sites, we considered the proximity of grassland sites to elements in the heterogeneity layers via the "Ecological Interactions" option in Zonation. This means that the heterogeneity elements were not prioritized themselves, but they influenced the prioritization ranking value of the grassland sites based on how far the elements were situated from the grassland site under consideration. The scale for this influence was also set to two km. This means that, when other prioritization elements are equal, a grassland site falling within the two-km connectivity kernel around a heterogeneity element will receive a higher heterogeneity value and thus rank higher in the Zonation prioritization than a grassland falling outside the two-km connectivity kernels. Thus, the influences of connectivity and landscape heterogeneity on grassland prioritization were set at an equal level.

Zonation functions for landscape analyses

First, we applied the option of transformed layers output -function in Zonation. Zonation calculates connectivity transformations onto all input biodiversity feature layers (Table 1) prior to the actual ranking process, and this function produces output maps of these transformed input layers (Moilanen et al. 2014). It simultaneously considers size, form, arrangement and weight of the landscape heterogeneity data in relation to the grassland data. The transformed layers allowed us to directly and separately view the effects of the compositional and configurational landscape heterogeneity elements, and connectivity of the grassland parcels prior to Zonation ranking. This examination allowed us to detect spatial patterns and correlations among the various factors.

Second, we carried out two sets of actual Zonation prioritization analyses: (1) "Basic" analysis, which included the prioritization of conservation value on grassland data only and (2) "Landscape" analysis where we added landscape heterogeneity elements into the prioritization. We replicated both analyses with grassland-to-grassland connectivity, resulting in a total of four priority rank maps. The grassland data (data sets 1, 2 and partially 3; see Table 1) were the only data that were ranked in the Zonation prioritization. In contrast, the heterogeneity data were not ranked, but used indirectly to drive the priorities towards more heterogeneous landscapes.

We used the Additive benefit function -variant of Zonation, which takes into account all weighted features in a cell instead of only the highest feature value, i.e. all biodiversity features (Table 1 and Fig. 2) in a given cell are summed. This function variant is considered most appropriate when the features are essentially surrogates for species such as the habitat types in our study.

Post-processing of results

We calculated correlations between the three transformed output layers (i.e. habitat connectivity and compositional and configurational heterogeneity). The correlations and significance values were obtained with the Raster package in R v3.2.1 (R Development Core Team 2008). Correlation coefficients depict the relationship between two raster layers, which is a measure of dependency between the layers. A positive correlation indicates a direct relationship between two layers, whereas a negative correlation means that one variable changes inversely to the other.

Hierarchical priority rankings produced in the analysis were customized into selected top fractions for cartographical use and charts in ArcGIS and R. These categorizations visualized the differences between each analysis variant.

Results

The application of transformed output layers prior to the actual prioritization showed that landscape elements improving ecological quality and compositional heterogeneity coincide with high grassland connectivity. A very strong positive correlation was observed between grassland site connectivity and (land cover type -based) compositional landscape heterogeneity, whereas correlations were lower for the other pair-wise comparisons (Table 2). Note that all correlations are high because they result from the transformations made on the same raw data layers, and thus it is necessary to focus on the relative differences between different pairwise comparisons rather than absolute values.

Table 2 Pearson's correlation coefficients of transformed input layers produced by Zonation prior to the actual prioritization ranking process. Highest positive correlation (0.92) indicates that better-connected grassland sites are located in landscapes with higher (land cover type -based) compositional heterogeneity than (field margin -based) configurational heterogeneity.

	Correlation coefficients		
	Compositional heterogeneity	Configurational heterogeneity	Connectivity
Compositional heterogeneity	1	0.71*	0.92*
Configurational heterogeneity	0.71*	1	0.62*
Connectivity	0.92*	0.62*	1

*p < 0.01

This result indicates that valuable, well-connected grasslands tend to cluster especially in landscapes where landscape elements beneficial to biodiversity are more abundant.

Our multi-objective prioritization analyses were simultaneously able to account for local habitat quality, landscape heterogeneity and connectivity. Broader-scale biodiversity targets (i.e. connectivity and landscape heterogeneity) resulted in solutions where local habitat quality targets were compromised and not fully optimal (Figs. 3 and 4, d). When these trade-offs occurred, some of the most valuable semi-natural grasslands based on local habitat quality were lost from the topmost 10% conservation priority fraction due to poor connectivity and low landscape heterogeneity (Figs. 3 and 4, a–d).

We also detected various grades of trade-offs between different landscape-level objectives. Local habitat quality was compromised very slightly when only landscape heterogeneity (both compositional and configurational) (Fig. 3, b) was included in the prioritization, whereas connectivity (Fig. 3, c) resulted in greater trade-offs in the top 10% fractions. Including both connectivity and landscape heterogeneity into prioritization resulted in the largest boost in the trade-off effect (Figs. 3 and 4, d). Moreover, certain sites were valuable based on their local habitat quality, but which concurrently were both isolated and occurred in landscapes that were not particularly heterogeneous.

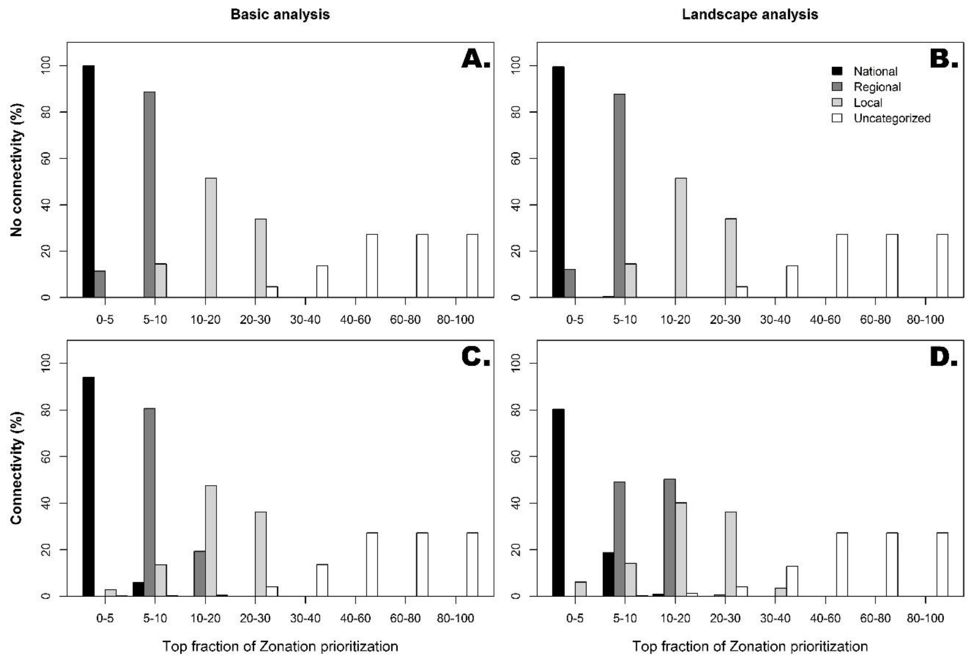

Fig. 3 Division of grassland data in Zonation prioritization ranking into different top fractions in ”Basic” and ”Landscape” analyses with and without connectivity. The X-axis shows how the prioritized grassland data falls into different top fractions and the y-axis shows the percentage of each grassland category left in different top fractions, e.g. in panel (d) the top 5% fraction of cells contains 80% of all nationally valuable semi-natural grasslands. Changes in the top fraction of various analysis variants illustrate the trade-offs for local habitat quality. The greatest loss of most valuable semi-natural grasslands from the top priority fraction can be found when both landscape heterogeneity and connectivity are integrated in landscape-level prioritization (d compared to a). Landscape heterogeneity alone does not result in a trade-off with local habitat quality (b compared to a). Connectivity alone results in modest trade-offs with local habitat quality (c compared to a).

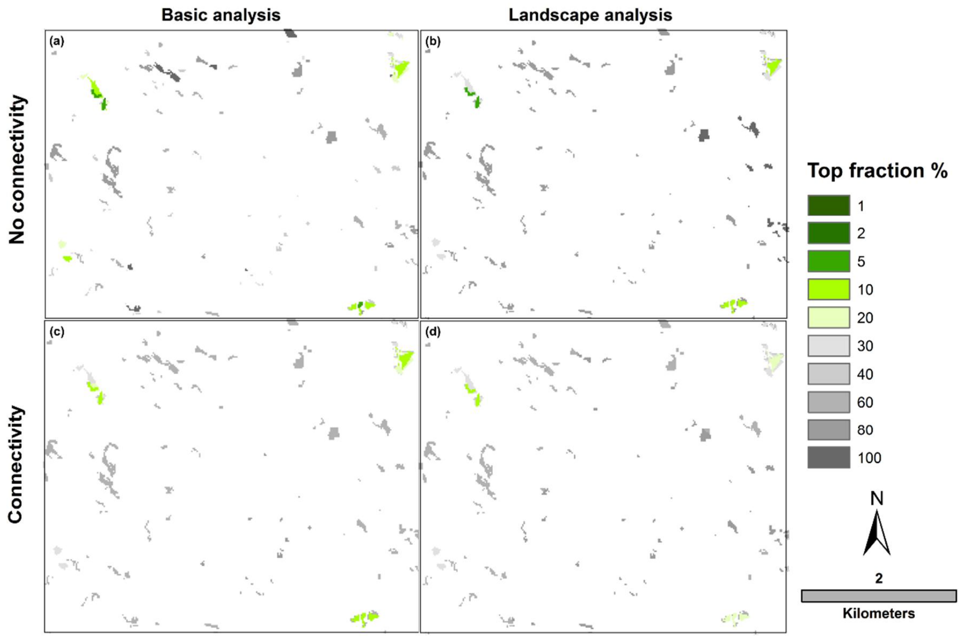

Fig. 4 An example of Zonation priority ranking maps, showing various prioritization outcomes between the analysis variants. (a) Basic analysis without connectivity, where only grassland data weights directed the prioritization, (b) Landscape analysis, where both compositional and configurational landscape heterogeneity weights directed the prioritization of grassland data. (c) Basic analysis, where connectivity also (two km) directed the prioritization of grassland data. (d) Landscape analysis, where all variables, including connectivity (two km), compositional and configurational landscape heterogeneity weights directed the prioritization of grassland data.

Discussion

We included both land-sparing (species-rich grassland habitats) and land-sharing (compositional and configurational heterogeneity) aspects along with their connectivity into our multi-objective broader-scale spatial conservation prioritization. These aspects determine many key ecological processes, which influence biodiversity in agricultural environments.

The key finding emerging from our prioritization results is that landscape elements that improve ecological quality and compositional heterogeneity coincide with high grassland connectivity. This result has certain implications for the targeting of AES support to the management of semi-natural grasslands, and to the identification of candidate sites for habitat restoration. Such synergies highlight the importance of tackling AES allocation as a landscape-level or regional interconnected process instead of considering the management of each semi-natural grassland site in a given region separately from the others.

Because of a drastic decrease in the amount of semi-natural grassland habitats in past decades the sparing of these habitats has been seen as the primary conservation objective (Prevedello and Vieira 2010; Hodgson et al. 2011; Ekroos et al. 2016). In our conservation prioritization we emphasized the importance of high-quality semi-natural grassland habitat over habitat quantity because other grassland habitats included in our study landscape are unlikely to provide additional high-quality habitats for threatened and declined grassland species. This is supported by Ekroos et al. (2016), who emphasize that traditional semi-natural grasslands usually have a long management history that has generated distinctive animal and plant species compositions (and, for example, associated seed banks) that cannot easily be substituted by other younger grasslands.

However, the role of grassland sites with lower local quality should not be downplayed. This is because these sites may support farmland biodiversity by enhancing connectivity and the probability of dispersal between high-quality sites. They may also provide potential sites for restoration, especially when located close to high-quality grassland sites. More generally, as illustrated by our analysis, inclusion of grassland sites with lower local quality in broader-scale prioritization can enhance the consideration of multi-objective landscape-level ecological processes.

In many areas the decrease in semi-natural grassland habitats has led to habitat fragmentation, which decreases connectivity and compositional landscape heterogeneity by reducing the number and size of habitats and increases their unfavourable arrangement (Brückmann et al. 2010; Perović et al. 2015). Effective semi-natural grassland biodiversity conservation outcomes cannot therefore be achieved only through sparing land, but acknowledging the significance of the surrounding farmland matrix quality is essential (Söderström et al. 2001; Eycott et al. 2012; Rösch et al. 2013; Slancarova et al. 2013; Janišová et al. 2014). These arguments were supported by our conservation prioritization results that showed trade-offs of isolated high-quality patches in less heterogeneous landscapes, indicating that sparing habitat quantity and quality alone does not lead to optimal conservation outcomes. However, it should be noted that even small habitat fragments can maintain overall biodiversity when their spatial arrangement is favourable, i.e. when they are well-connected (Tscharntke et al. 2002; Tscharntke et al. 2012).

The land-sharing approach generates a more heterogeneous landscape where many habitat generalists may profit from secondary patches as complementary resources and movement facilitators (Tscharntke et al. 2012). In our conservation prioritization, areas with higher compositional heterogeneity also maintained higher connectivity. This infers that increasing crop production intensity has had agglomerating biodiversity degradation effects. According to our prioritization analysis, relatively high configurational heterogeneity was occasionally preserved even in otherwise homogeneous and intensively farmed areas in the form of dense field margin networks. The coincidence of well-connected grassland habitats and compositional heterogeneity in our conservation prioritization could benefit the directed land-sparing approach. This is in line with the results of Ekroos et al. (2016), which indicated that devoting specific areas of non-crop habitats to conservation outside intensive crop production could lead to more effective biodiversity conservation.

The existing EU Common Agricultural Policy contains both land-sparing and land-sharing management actions as incentive for farmers to adopt biodiversity-friendly farming practices. Our Zonation-based demonstration illustrates how the spatial arrangement of an equivalent number of various biodiversity elements may vary between differently weighted conservation prioritizations. This implies high flexibility and potential for the reconstruction of a functioning network of semi-natural grasslands even in areas under intensive agricultural use. Moreover, our conservation prioritization enables the identification of those area networks that would benefit from targeted AES measures.

In light of this, AES effectiveness as a part of biodiversity conservation strategy might be improved without additional financial inputs, if regionally better coordinated management actions would be readily available and adopted by farmers. This would support institutional development and participation of stakeholders in complex social-ecological farming systems as recommended by Hodge et al. (2015) and improve targeting, monitoring and evaluating biodiversity actions (Lomba et al. 2017). We believe that multi-objective optimization considering both land-sharing and -sparing aspects can help with targeting biodiversity conservation more effectively in situations with socio-economical pressure caused by demand for food production and agricultural industry and can help mediate the implementation of CAP objectives.

Acknowledgements

A.H. was supported by a grant from the Kone Foundation. Aija Kukkala and Ninni Mikkonen made valuable comments on earlier versions and helped to improve the manuscript.

References

Arponen A, Heikkinen R, Paloniemi R, et al (2013) Improving conservation planning for semi-natural grasslands: Integrating connectivity into agri-environment schemes. Biol Conserv 160:234–241. doi: doi:10.1016/j.biocon.2013.01.018

Auffret AG, Cousins SAO (2011) Past and present management influences the seed bank and seed rain in a rural landscape mosaic. J Appl Ecol 48:1278–1285. doi: 10.1111/j.1365-2664.2011.02019.x

Batáry P, Báldi A, Kleijn D, Tscharntke T (2011) Landscape-moderated biodiversity effects of agri-environmental management: a meta-analysis. Proc Biol Sci 278:1894–902. doi: 10.1098/rspb.2010.1923

Batáry P, Dicks L V, Kleijn D, Sutherland WJ (2015) The role of agri-environment schemes in conservation and environmental management. Conserv Biol 29:1006–16. doi: 10.1111/cobi.12536

Bengtsson J, Ahnström J, Weibull A-C (2005) The effects of organic agriculture on biodiversity and abundance: a meta-analysis. J Appl Ecol 42:261–269. doi: 10.1111/j.1365-2664.2005.01005.x

Brückmann S V., Krauss J, Steffan-Dewenter I (2010) Butterfly and plant specialists suffer from reduced connectivity in fragmented landscapes. J Appl Ecol 47:799–809. doi: 10.1111/j.1365-2664.2010.01828.x

Butsic V, Kuemmerle T (2015) Using optimization methods to align food production and biodiversity conservation beyond land sharing and land sparing. Ecol Appl 25:589–595. doi: 10.1890/14-1927.1

Concepción ED, Fernández-González F, Díaz M (2012) Plant diversity partitioning in Mediterranean croplands: effects of farming intensity, field edge, and landscape context. Ecol Appl 22:972–981. doi: 10.1890/11-1471.1

Cousins SAO, Auffret AG, Lindgren J,

Tränk L (2015) Regional-scale land-cover change during the 20th century and its consequences for biodiversity. Ambio 44:17–27. doi: 10.1007/s13280-014-0585-9

de Bello F, Lavorel S, Gerhold P, et al (2010) A biodiversity monitoring framework for practical conservation of grasslands and shrublands. Biol Conserv 143:9–17. doi: 10.1016/j.biocon.2009.04.022

Dengler J, Janišová M, Török P, Wellstein C (2014) Biodiversity of Palaearctic grasslands: a synthesis. Agric Ecosyst Environ 182:1–14. doi: 10.1016/j.agee.2013.12.015

Duelli P (1997) Biodiversity evaluation in agricultural landscapes: An approach at two different scales. Agric Ecosyst Environ 62:81–91. doi: 10.1016/S0167-8809(96)01143-7

EEA (2012) European Environment Agency. Land cover 2006 and changes country analysis. http://www.eea.europa.eu/data-and-maps/figures/land-cover-2006-and-changes#tab-metadata. Accessed 25 Mar 2016

Ekroos J, Olsson O, Rundlöf M, et al (2014) Optimizing agri-environment schemes for biodiversity, ecosystem services or both? Biol Conserv 172:65–71. doi: 10.1016/j.biocon.2014.02.013

Ekroos J, Ödman AM, Andersson GKS, et al (2016) Sparing Land for Biodiversity at Multiple Spatial Scales. Front Ecol Evol 3:1–11. doi: 10.3389/fevo.2015.00145

Eycott AE, Stewart GB, Buyung-Ali LM, et al (2012) A meta-analysis on the impact of different matrix structures on species movement rates. Landsc Ecol 27:1263–1278. doi: 10.1007/s10980-012-9781-9

Fahrig L, Baudry J, Brotons L, et al (2011) Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecol Lett 14:101–12. doi: 10.1111/j.1461-0248.2010.01559.x

Ferrier S, Wintle BA (2009) Quantitative Approaches to Spatial Conservation Prioritization: Matching the Solution to the Need. In: Moilanen A, Wilson KA, Possingham HP (eds) Spatial Conservation Prioritization Quantitative Methods & Computational Tools. Oxford University Press, New York, NY, p 304

Fischer J, Abson DJ, Butsic V, et al (2014) Land Sparing Versus Land Sharing: Moving Forward. Conserv Lett 7:149–157. doi: 10.1111/conl.12084

Fischer J, Brosi B, Daily GC, et al (2008) Should agricultural policies encourage land sparing or wildlife-friendly farming? Front Ecol Environ 6:380–385. doi: 10.1890/070019

Gonthier DJ, Ennis KK, Farinas S, et al (2014) Biodiversity conservation in agriculture requires a multi-scale approach. Proc Biol Sci 281:20141358. doi: 10.1098/rspb.2014.1358

Green RE, Cornell SJ, Scharlemann JPW, Balmford A (2005) Farming and the fate of wild nature. Science 307:550–5. doi: 10.1126/science.1106049

Habel JC, Dengler J, Janišová M, et al (2013) European grassland ecosystems: threatened hotspots of biodiversity. Biodivers Conserv 22:2131–2138. doi: 10.1007/s10531-013-0537-x

Hanski I (1998) Metapopulation dynamics. Nature 396:41–49. doi: 10.1038/23876

Herzon I, Helenius J (2008)

Agricultural drainage ditches, their biological importance and functioning. Biol Conserv 141:1171–1183. doi: 10.1016/j.biocon.2008.03.005

Hicks K (2010) Assessing biodiversity in Europe — the 2010 report. EEA report No 5/2010.

Hodge I, Hauck J, Bonn A (2015) The alignment of agricultural and nature conservation policies in the European Union. Conserv Biol 29:996–1005. doi: 10.1111/cobi.12531

Hodgson JA, Moilanen A, Wintle BA, Thomas CD (2011) Habitat area, quality and connectivity: striking the balance for efficient conservation. J Appl Ecol 48:148–152. doi: 10.1111/j.1365-2664.2010.01919.x

Janišová M, Michalcová D, Bacaro G, Ghisla A (2014) Landscape effects on diversity of semi-natural grasslands. Agric Ecosyst Environ 182:47–58. doi: 10.1016/j.agee.2013.05.022

Juffe-Bignoli D, Burgess ND, Bingham H, et al (2014) Protected Planet Report 2014. Cambridge, UK

Kleijn D, Baquero RA, Clough Y, et al (2006) Mixed biodiversity benefits of agri-environment schemes in five European countries. Ecol Lett 9:243-54–7. doi: 10.1111/j.1461-0248.2005.00869.x

Kleijn D, Rundlöf M, Scheper J, et al (2011) Does conservation on farmland contribute to halting the biodiversity decline? Trends Ecol Evol 26:474–81. doi: 10.1016/j.tree.2011.05.009

Kremen C (2015) Reframing the land-sparing/land-sharing debate for biodiversity conservation. In: Annals of the New York Academy of Sciences. pp 52–76

Kuussaari M, Heliölä J, Luoto M, Pöyry J (2007) Determinants of local species richness of diurnal Lepidoptera in boreal agricultural landscapes. Agric Ecosyst Environ 122:366–376. doi: 10.1016/j.agee.2007.02.008

Lomba A, Strohbach M, Jerrentrup JS, et al (2017) Making the best of both worlds: Can high-resolution agricultural administrative data support the assessment of High Nature Value farmlands across Europe? Ecol Indic 72:118–130. doi: 10.1016/j.ecolind.2016.08.008

Ma M, Hietala R, Kuussaari M, Helenius J (2013) Impacts of edge density of field patches on plant species richness and community turnover among margin habitats in agricultural landscapes. Ecol Indic 31:25–34. doi: 10.1016/j.ecolind.2012.07.012

Margules CR, Pressey RL (2000) Systematic conservation planning. Nature 405:243–253. doi: 10.1038/35012251

Marshall EJP, Moonen A. (2002) Field margins in northern Europe: their functions and interactions with agriculture. Agric Ecosyst Environ 89:5–21. doi: DOI: 10.1016/S0167-8809(01)00315-2

McKenzie AJ, Emery SB, Franks JR, Whittingham MJ (2013) Landscape-scale conservation: collaborative agri-environment schemes could benefit both biodiversity and ecosystem services, but will farmers be willing to participate? J Appl Ecol 50:1274–1280. doi: 10.1111/1365-2664.12122

Moilanen A, Anderson BJ, Eigenbrod F, et al (2011) Balancing alternative land uses in conservation prioritization. Ecol Appl 21:1419–1426. doi: 10.1890/10-1865.1

Moilanen A, Franco AMA, Early RI, et al (2005) Prioritizing multiple-use landscapes for conservation: methods for large multi-species planning problems. Proc Biol Sci 272:1885–91. doi: 10.1098/rspb.2005.3164

Moilanen A, Nieminen M (2002) Simple connectivity measures in spatial ecology. Ecology 83:1131–1145. doi: DOI: 10.1890/0012-9658(2002)083[1131:SCMISE]2.0.CO;2

Moilanen A, Pouzols FM, Meller L, et al (2014) Spatial conservation planning methods and sofware Zonation. Version 4. User manual. University of Helsinki

Official Statistics of Finland (2015) Utilised Agricultural Area [e-publication]. Natural Resources Institute Finland. http://www.stat.fi/til/kaoma/index_en.html. Accessed 25 Mar 2016

Perović D, Gámez-Virués S, Börschig C, et al (2015) Configurational landscape heterogeneity shapes functional community composition of grassland butterflies. J Appl Ecol 52:505–513. doi: 10.1111/1365-2664.12394

Prevedello JA, Vieira M V. (2010) Does the type of matrix matter? A quantitative review of the evidence. Biodivers Conserv 19:1205–1223. doi: 10.1007/s10531-009-9750-z

Pykälä J (2000) Mitigating Human Effects on European Biodiversity through Traditional Animal Husbandry. Conserv Biol 14:705–712. doi: 10.1046/j.1523-1739.2000.99119.x

R Development Core Team (2008) R: a language and environment for statistical computing. In: Vienna, Austria R Found. Stat. Comput. ISBN 3-900051-07-0. Available online http//www.R-project.org/. http://www.gbif.org/resource/81287. Accessed 2 Sep 2015

Rösch V, Tscharntke T, Scherber C, Batáry P (2013) Landscape composition, connectivity and fragment size drive effects of grassland fragmentation on insect communities. J Appl Ecol 50:387–394. doi: 10.1111/1365-2664.12056

Šálek M, Kučera T, Zimmermann K, et al (2015) Edges within farmland: Management implications of taxon specific species richness correlates. Basic Appl Ecol 16:714–725. doi: 10.1016/j.baae.2015.08.001

Scheper J, Holzschuh A, Kuussaari M, et al (2013) Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss--a meta-analysis. Ecol Lett 16:912–20. doi: 10.1111/ele.12128

Schooley RL, Branch LC (2011) Habitat quality of source patches and connectivity in fragmented landscapes. Biodivers Conserv 20:1611–1623. doi: 10.1007/s10531-011-0049-5

Slancarova J, Benes J, Kristynek M, et al (2013) Does the surrounding landscape heterogeneity affect the butterflies of insular grassland reserves? A contrast between composition and configuration. J Insect Conserv 18:1–12. doi: 10.1007/s10841-013-9607-3

Smith HG, Dänhardt J, Lindström Å, Rundlöf M (2010) Consequences of organic farming and landscape heterogeneity for species richness and abundance of farmland birds. Oecologia 162:1071–9. doi: 10.1007/s00442-010-1588-2

Stoate C, Báldi A, Beja P, et al (2009) Ecological impacts of early 21st century agricultural change in Europe - a review. J Environ Manage 91:22–46. doi:

10.1016/j.jenvman.2009.07.005

Söderström B, Svensson B, Vessby K, Glimskär A (2001) Plants, insects and birds in semi-natural pastures in relation to local habitat and landscape factors. Biodivers Conserv 10:1839–1863. doi: 10.1023/A:1013153427422

Teillard F, Doyen L, Dross C, et al (2016) Optimal allocations of agricultural intensity reveal win-no loss solutions for food production and biodiversity. Reg Environ Chang 1–12. doi: 10.1007/s10113-016-0947-x

Tscharntke T, Klein A-M, Kruess A, et al (2005) Landscape perspectives on agricultural intensification and biodiversity - ecosystem service management. Ecol Lett 8:857–874. doi: 10.1111/j.1461-0248.2005.00782.x

Tscharntke T, Steffan-Dewenter I, Kruess A, Thies C (2002) Contribution of small habitat fragments to conservation of insect communities of grassland-cropland landscapes. Ecol. Appl. 12:354–363.

Tscharntke T, Tylianakis JM, Rand TA, et al (2012) Landscape moderation of biodiversity patterns and processes - eight hypotheses. Biol Rev Camb Philos Soc 87:661–85. doi: 10.1111/j.1469-185X.2011.00216.x

Tuck SL, Winqvist C, Mota F, et al (2014) Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis. J Appl Ecol 51:746–755. doi: 10.1111/1365-2664.12219

Vainio M, Kekäläinen H, Alanen A, Pykälä J (2001) Traditional rural biotopes in Finland. Final report of the nationwide inventory. Finnish Environment Institute. Series 527., Vammala

van Swaay C, Maes D, Collins S, et al (2011) Applying IUCN criteria to invertebrates: How red is the Red List of European butterflies? Biol Conserv 144:470–478. doi: 10.1016/j.biocon.2010.09.034

Whittingham MJ (2007) Will agri-environment schemes deliver substantial biodiversity gain, and if not why not? J Appl Ecol 44:1–5. doi: 10.1111/j.1365-2664.2006.01263.x

Winqvist C, Ahnström J, Bengtsson J (2012) Effects of organic farming on biodiversity and ecosystem services: taking landscape complexity into account. Ann N Y Acad Sci 1249:191–203. doi: 10.1111/j.1749-6632.2011.06413.x

Öckinger E, Smith HG (2006) Landscape composition and habitat area affects butterfly species richness in semi-natural grasslands. Oecologia 149:526–534. doi: 10.1007/s00442-006-0464-6

Öster M, Cousins SAO, Eriksson O (2007) Size and heterogeneity rather than landscape context determine plant species richness in semi-natural grasslands. J Veg Sci 18:859–868. doi: 10.1111/j.1654-1103.2007.tb02602.x

Integrating social and ecological knowledge for targeting voluntary biodiversity conservation

Paloniemi, R., Hujala, T., Rantala, S., Harlio, A., Salomaa, A., Primmer, E., Pynnönen, S. and Arponen, A.

Conservation Letters. Accepted 23 December 2016.

Conservation Letters

A journal of the Society for Conservation Biology

Open Access

LETTER

Integrating Social and Ecological Knowledge for Targeting Voluntary Biodiversity Conservation

Riikka Paloniemi[1], Teppo Hujala[2,3], Salla Rantala[1], Annika Harlio[4], Anna Salomaa[5], Eeva Primmer[1], Sari Pynnönen[6], & Anni Arponen[4]

[1] Environmental Policy Centre, Finnish Environment Institute (SYKE), Helsinki, Finland
[2] Natural Resources Institute Finland (Luke), Bio-based Business and Industry, Helsinki, Finland
[3] University of Eastern Finland (UEF), School of Forest Sciences, Joensuu, Finland
[4] Metapopulation Research Centre, Department of Biosciences, University of Helsinki, Helsinki, Finland
[5] Department of Environmental Sciences, University of Helsinki, Helsinki, Finland
[6] Central Union of Agricultural Producers and Forest Owners (MTK), Helsinki, Finland

Keywords
Conservation targeting; dialogue; landowner; prioritization; survey; voluntary conservation; Zonation software .

Correspondence
Riikka Paloniemi, Environmental Policy Centre, Finnish Environment Institute (SYKE), P.O. Box 140, Helsinki FIN-00251, Finland. Tel: +358 40 7017 250; fax: +358 9 5490 2190.
E-mail: riikka.paloniemi@ymparisto.fi

Received
15 August 2016
Accepted
23 December 2016

doi: 10.1111/conl.12340

Abstract

Improving the effectiveness of voluntary biodiversity policies requires developing trans-disciplinary conservation plans that consider social constraints to achieving ecological objectives. We integrated data on landowners' willingness to participate in voluntary conservation efforts with ecological data on conservation values in a spatial prioritization, and found that doing so considerably reduced the loss in conservation value caused by landowners' reluctance to participate. We learned that conducting prioritization with stakeholder input gained through dialogue during field visits could be beneficial for increasing the legitimacy of conservation plans with stakeholders. Thus, in addition to developing a methodology for using data on stakeholder perceptions of conservation in spatial prioritization, our study suggests that engaging landowners and other stakeholders in the conservation prioritization process will improve the success of conservation plans.

Introduction

International conservation efforts have so far failed to stop the loss of biodiversity (Tittensor et al. 2014). Efforts to expand and consolidate state-managed protected area networks (Jenkins & Joppa 2009) and improve the management of existing protected areas (Le Saout et al. 2013) are not sufficient to protect biodiversity. Engagement of practitioners and landowners is also necessary (Tallis & Lubchenco 2014). Voluntary conservation approaches involving private landowners and communities with a stake in biodiversity conservation are important for broadening conservation practices (Mayer & Tikka 2006; Selinske et al. 2015). A prevalent challenge for voluntary approaches is implementing conservation actions in places that achieve ecological objectives, while accounting for landowners' propensity to participate in voluntary conservation activities (Mönkkönen et al. 2009).

The field of spatial conservation prioritization supports conservation planning that improves the cost-efficiency and connectivity of conservation areas. Spatial conservation prioritization is primarily founded on biological knowledge and often does not consider sociopolitical constraints on conservation actions (Knight et al. 2011; Whitehead et al. 2014). The techniques used for spatial prioritization can account for biological, economic, and social constraints and produce alternative cost-efficient solutions (Moilanen et al. 2009; Klein et al. 2013). However, the practical application of information on social constraints to conservation actions, such as landowners' reluctance to get involved in conservation, remains a challenge.

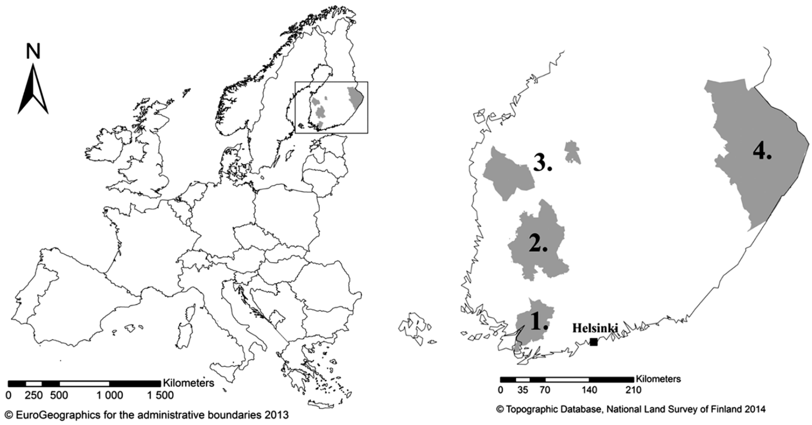

Figure 1 Study areas. The study areas are presented in the map in gray. 1 = Rekijokilaakso-Hyyppärä region; 2 = Pirkanmaa region; 3 = Southern Ostrobothnia; 4 = Northern Karelia. The landowner survey and the dialogue workshops were carried out in all areas (including a joint workshop in areas 2 and 3), and the spatial conservation prioritization analysis was conducted in the Rekijokilaakso-Hyyppärä region.

Where landowners oppose centrally designed conservation plans, voluntary contracting can increase acceptance of conservation plans, because it respects landowner autonomy over land use decisions (Paloniemi & Tikka 2008; Paloniemi & Vainio 2011). Thus, the prioritization of voluntary conservation actions should consider the willingness of landowners to participate in voluntary contracts. However, a voluntary approach may not allocate conservation resources efficiently (Doremus 2003), particularly on a landscape scale. Consequently, voluntary conservation reliant on landowners' perspectives should be integrated into systematic conservation planning made at landscape scale (Grantham et al. 2010; Knight et al. 2011).

Voluntary contracts for conservation actions are exemplified in Finland. In Finland, private landowners' voluntary contracts for state-subsidized conservation are a central instrument under the ongoing Forest Biodiversity Program (Government of Finland 2014). However, the approach faces challenges for conservation effectiveness, because family forest estates are relatively small (30 hectares on average; Peltola 2014) and landowners' perceptions, motivations, and previous experiences of conservation as well as willingness to engage in conservation vary across the landscape (Primmer et al. 2014). Thus, voluntary conservation actions by individual landowners do not necessarily result in an ecologically optimal conservation network at landscape scale. In this article, we investigate how landowners' (un)willingness to participate in conservation actions that cross the boundaries of individual forest estates affects conservation outcomes.

We develop an approach that combines information on landowners' willingness to participate in voluntary initiatives with an optimization of conservation actions that targets ecological goals set at landscape level. To analyze how voluntary biodiversity conservation can be used to target conservation actions, we sought to answer the following questions:

(i) How do landowners perceive landscape-level biodiversity conservation across property boundaries?
(ii) What are the opportunities and limitations for integrating landowner perceptions with biological datasets in prioritization analyses that aim to achieve landscape-level ecological objectives?
(iii) What are the possibilities of multistakeholder collaboration to support the application of integrated prioritization and voluntary, landscape-level conservation in practice?

Methods

We combined data from a landowner survey, spatial conservation prioritization, and multistakeholder dialogue workshops. The study focused on southern Finland (Figure 1). The study areas were selected to cover a comprehensive spectrum of social and environmental contexts. They contain southwestern, western, central and eastern regions; forestry-dominated, agriculture-dominated and mixed landscapes; and varied in the extent of voluntary conservation efforts.

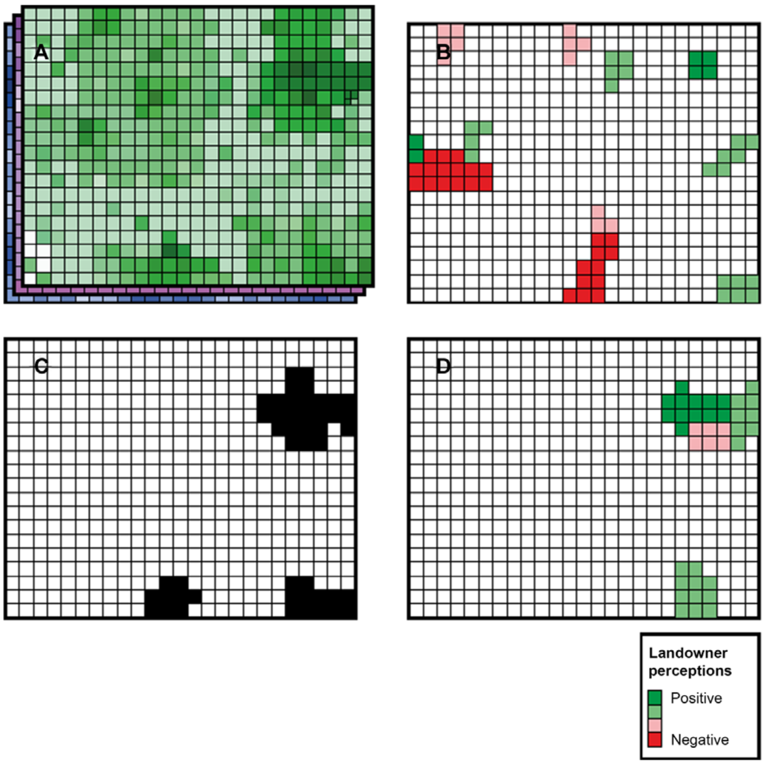

Figure 2 Schematic illustrating the spatial datasets for the Rekijoki-Hyyppärä region. We had multiple layers of spatial ecological data for use in Zonation (A). To obtain data on landowner perceptions, a questionnaire was sent to all private forest owners in the region, but responses were not received from all landowners (B). Zonation prioritization indicated where the highest priorities for ecological values were (C) and we complemented our questionnaire data by focusing on owners of forests that overlapped or were close to the high priority Zonation sites and around landowners with positive perceptions (D). The forest owners in the complementary sample were asked to respond only to the questions to be used in the spatial analysis.

Landowner survey

We quantitatively measured landowner perceptions on landscape-level conservation by mailing a questionnaire to randomly sampled and systematically selected owners of forests within the study areas (Figure 1, Annex A). After a reminder, 509 completed questionnaires were returned (response rate 23%) in April to May 2014. To cover more landowners in the *Rekijokilaakso-Hyyppärä* region where the spatial prioritization analysis was performed, we conducted follow-up interviews by phone in that region (Figure 2, Annex A). This complementary survey for the *Rekijokilaakso-Hyyppärä* region resulted in 32 new responses, producing a data set consisting of a total of 541 responses, of which 144 were from *Rekijokilaakso-Hyyppärä*. Profiles of the respondents and nonrespondents are provided in Annex B.

Perceptions about conservation were assessed by asking the respondents to rate a number of statements related to the principles and means of safeguarding biodiversity (Table 1). The statements were formulated to assess views on conservation values and attitudes, perceptions of fairness, and rationales for compensation. Statements were constructed on the basis of earlier research on forest conservation instruments (Parkhurst et al. 2002; Mayer & Tikka 2006; Paloniemi & Tikka 2008; Paloniemi & Vainio 2011; Primmer et al. 2014). The statement set was tested with landowner representatives and pilot participants before the questionnaire was sent to landowners. Respondents were also asked whether they had previously made various conservation decisions: temporary or permanent conservation contracts with nature conservation authorities or forestry authorities;

Table 1 Biodiversity conservation perceptions of landowners in southern Finland, identified through Exploratory Factor Analysis. Values indicate loadings from the factor analysis. Loadings with absolute value greater than 0.400 are in bold font to indicate which statements are interpreted to relate to each factor. The analysis is based on the responses to the survey questions (i) "*How important are the following aspects in safeguarding biodiversity in your opinion*" (the respondents were asked to first give a value of "5" to the 1–3 aspects perceived to be the most important, then give a value of "1" to 1–3 aspects that were perceived to be the least important, and, finally, to give values of "2"–"4") to the remaining aspects and (ii) "*The following statements describe the implementation of the Forest Biodiversity Program. Do you agree with the statements?*" (evaluated on a scale from 1 [totally disagree] to 5 [totally agree])

	Factor					
	1 Cross-boundary conservation efforts	2 Safeguarding biodiversity	3 Agglomeration bonus	4 Social norm	5 Economic benefit	6 Just a contract
Conservation efforts that cross the boundaries of forest sites and estates should be promoted more	**0.856**	0.190	0.013	0.071	–0.074	0.050
Neighboring forest owners should cooperate more to conserve biodiversity	**0.783**	0.158	0.119	0.074	–0.075	0.111
Personally, I would be ready to cooperate with my neighbors to establish a larger protected area network	**0.687**	0.127	–0.019	0.147	–0.006	0.380
Currently, biodiversity conservation is too often implemented by focusing on individual forest sites only	**0.665**	0.201	0.196	0.094	0.107	–0.215
It is important that a conservation area network constitutes an ecologically functional network	**0.556**	0.377	0.113	–0.001	–0.081	0.147
I ensure that a site important for me personally is protected	0.167	**0.762**	–0.018	0.107	0.023	0.108
I aim to preserve the (protected) site in its natural state	0.195	**0.683**	0.063	0.034	0.053	0.253
All species are needed in biodiversity-rich nature	0.129	0.380	0.074	0.145	–0.124	–0.113
It is the responsibility of human beings to conserve nature	0.235	0.379	0.010	0.031	–0.196	–0.085
Compensation for voluntary conservation should be weighted depending on the significance of the site for a conservation area network	0.114	0.092	**0.792**	0.059	0.019	0.022
Higher compensation should be paid for a site located next to a protected area compared to a site located far from other protected areas	0.063	0.031	**0.707**	0.021	0.131	–0.071
I can improve recreational opportunities for the general public	0.059	0.081	0.036	**0.725**	0.173	–0.008
I respond to the expectations of other people	0.116	0.126	0.068	**0.648**	–0.065	0.050
I get financial benefits from conservation	–0.005	–0.047	0.099	–0.008	**0.614**	0.173
A temporary conservation contract does not bind future forest owners	–0.063	–0.060	0.065	0.068	**0.486**	–0.177
I am willing to make a conservation contract only if I am fully compensated for the value of timber	0.062	–0.030	0.358	0.090	0.321	0.205
I am willing to make new conservation contracts [to be included in the Forest Biodiversity Programme] if suitable sites exist on my land	**0.486**	0.211	0.012	0.057	0.068	**0.574**

land sale or exchange with nature conservation authorities; or informal efforts.

We analyzed landowner responses to the questionnaire using Exploratory Factor Analysis (e.g., Gorsuch 1988) (Table 1). Factor analysis is a multivariate method that enabled us to reduce the survey information from 17 statements into 6 unmeasured variables, termed factors. Analyses were performed using SPSS statistical software (version 23). We then used one factor that we interpreted to represent willingness to participate in conservation actions coordinated at landscape level in the spatial conservation prioritization.

Spatial conservation prioritization with Zonation

We carried out a conservation prioritization analysis for the *Rekijokilaakso-Hyyppärä* region (Figure 1), using the Zonation v4.0 software, a framework for spatial conservation prioritization (Moilanen et al. 2014). The Zonation algorithm is initialized with protection of the full landscape and then it iteratively removes the planning units contributing the least toward the objectives for protecting biodiversity. The results give the rank order in which planning units should be protected, which can be visualized as maps. Our objective was to cover the highest quality sites for the main forest types and wooded seminatural grasslands represented in our data.

Three different Zonation analyses were conducted: (1) prioritization based only on ecological data, representing a typical prioritization procedure conducted by conservation scientists or managers (*ecologically optimized*); (2) prioritization based on ecological data and landowner perceptions, representing how conservation can be optimized while considering an indicator of site availability (*integrated*); and (3) a post hoc analysis of the *ecologically optimized* prioritization with removal of sites where landowners had negative perceptions of conservation. Analysis (3) represented the outcome of an ecological prioritization where voluntary conservation contracts are not achieved in sites that were ranked high for their ecological value (*ecologically optimized excluding negative landowners*).

We produced gridded maps of habitat types using national forest inventory data from Finland (MS-NFI), and the Finnish national survey on the biotopes of wooded seminatural grasslands (Vainio et al. 2001; Tomppo 2006, Annex C). Each habitat type was given a weighting to reflect its conservation value relative to other habitat types. We accounted for connectivity between similar habitat types. Weights and connectivity parameters were based on Lehtomäki et al. (2009, Annex C).

For the *integrated* Zonation analysis (2), landowner perceptions were included as weightings on sites (Annex C). Weighting was proportional to the factor scores from the *cross-boundary conservation efforts* factor (median value for missing data, Annex C), which reflected willingness of a landowner to participate in conservation, and their willingness to coordinate conservation efforts with neighbors (i.e., Factor 1 in Table 1). A median value was used to the 79% of nonrespondent landowners in order to maintain connectivity in the landscape.

Dialogue workshops

To explore the stakeholders' perceptions on how the different information sources could support conservation that targets ecological goals set at landscape level in practice, we organized nine discussions in three workshops (in the Rekijokilaakso-Hyyppärä, Pirkanmaa, and Northern Karelia regions; Figure 1). Workshops involved 59 participants including local landowners (not overlapping with the survey respondents), forestry and conservation authorities, forestry professionals, researchers, and nature enthusiasts. Participant selection was based on nominations from regional experts and on snowball sampling (Salomaa et al. 2016). To elicit debate, the discussions were structured around statements concerning the implementation of environmental policies (Mickwitz 2003), including the Forest Biodiversity Program and the roles of different actors in landscape-level conservation (Annex D). The discussions were recorded and transcribed. The contents of the discussions were analyzed using NVivo software (Berg 2011; Bazeley & Jackson 2013), exploring how stakeholders discussed (i) possibilities to improve conservation outcomes through prioritization analyses and (ii) possibilities to integrate knowledge on social constraints into conservation planning in their practices.

Results

Landowners' conservation perceptions

The perceptions of those landowners who responded to the survey were analyzed and grouped into six factors (Table 1).

The *cross-boundary conservation efforts* factor captured the idea of promoting conservation across boundaries of individual forest estates. It encompassed the perceptions that conservation too often focused on a single forest site; there is a need to promote cross-boundary conservation efforts; neighboring landowners should cooperate more; and conservation areas should form an ecologically functional network. In addition, the factor included statements concerning personal willingness to conserve and cooperate with neighbors to create a larger conservation area. We used this factor in the *integrated* prioritization analysis because it represented in a single number the willingness of landowners to participate in landscape-level conservation planning.

The other factors were *safeguarding biodiversity,* which expressed personal commitment to conservation, *agglomeration bonus* that emphasized additional payments for conserving sites that complement the conservation network, *social norm* that focused on the sociocultural dimension of conservation, and *economic benefit* that underlined the economic benefits experienced by the landowner.

Forty-eight percent of the respondents reported that they had participated in at least one conservation oriented program. The most common formal conservation contracts were a temporary contract made with forestry authorities (21% of respondents) and a permanent private conservation area contracted with nature conservation authorities (2008 and after) (18%). Importantly, the *cross-boundary conservation efforts* factor correlated positively with contracts for permanent conservation areas (since 2008) (df = 316; $F = 9.567$; $P < 0.001$). In addition, 21% of respondents had privately set aside an area for conservation.

Integration of landowner perceptions with ecological data

The size and quality of a landowner's site and the surrounding landscape affected how strongly their perceptions influenced the prioritization results (Figures 3A–C). Where landowners with negative perceptions toward conservation were located next to landowners with positive perceptions toward conservation, the *integrated* analysis shifted the priority toward landowners with positive perceptions when compared with the *ecologically optimized* analysis (Figures 3A–C, area 1). Sites with moderately high conservation value also increased in importance if they aligned with positive perceptions (Figures 3A–C, area 2). No change in the ranking of an area was observed for areas with low ecological importance when comparing the *integrated* and *ecologically optimized* analyses (Figures 3A–C, areas 3 and 4). The perceptions of landowners with larger sites affected the prioritization results more than those of landowners with smaller sites, because Zonation associates large sites with increased conservation value due to higher connectivity.

The loss of conservation value due to predicted non-participation (negative perceptions) was 2.4% for the top 5% priority network (2.6% for top 10%), compared to the *ecologically optimized* analysis. When landowner perceptions were accounted for (*integrated*), the loss was only 1.1% (1% for the top 10%) (Figure 3D).

Spatial overlap among priority sites for the three solutions was lowest between the *integrated* and the *ecologically optimized* solutions (Figure 4). The *integrated* priorities were displaced from those of the *ecologically optimized* because some high-priority sites turned out to be unavailable due to negative landowner perceptions, which may cause Zonation to further shift priorities into places that provide better connectivity. Overlap between the *ecologically optimized* and the *ecologically optimized excluding negative landowners* solution was high because only a few critical sites were excluded (larger loss in Figure 3D than for the *integrated* solution).

Opportunities to improve targeted landscape-level conservation through collaboration

In the dialogue workshops, the participants discussed the pros and cons of prioritization analyses and whether conservation outcomes could be improved through enhanced interaction between different stakeholders. The participants viewed prioritization analyses as a future option rather than a current practice. Identified benefits of prioritization analyses included saving time and resources (in particular in contacting landowners), systematizing the identification of potential sites, the ability to consider larger landscapes and connectivity, and helping to find new sites for protecting threatened species.

Potential negative aspects of prioritization included the need for field visits to complement remote sensing-based analyses, the limited ability of the analysis to identify new areas of high ecological value in addition to those already known, the maintenance and updating of databases, and limited access to the information produced in the analyses by actors other than those conducting them. It was also questioned whether prioritization would help to conserve moving species or address trade-offs between different species and habitat types. In addition, lack of social data (i.e., information on landowners' willingness for conservation) was seen to restrict integrative analyses, the acquisition of which also required extra effort in this study.

It was pointed out that prioritization analyses, if conducted without involving local stakeholders, could be associated with past experiences of top-down, forced conservation and thus might work against the spirit of collaboration achieved through the Forest Biodiversity Program. The participants therefore recommended combining prioritization analyses with field visits in order to coproduce understanding of ecologically important areas and to allow face-to-face knowledge exchange and negotiation between landowners, officials, and other relevant

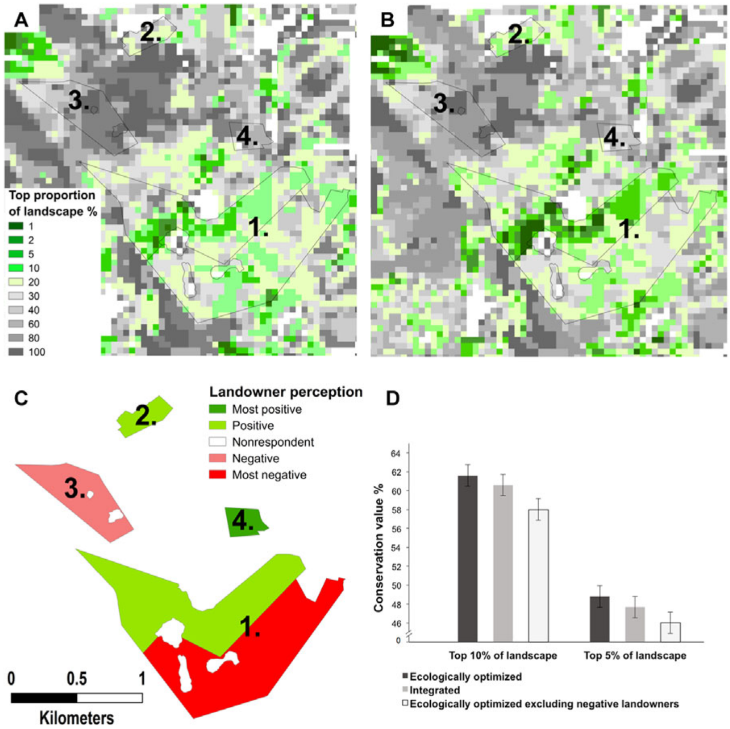

Figure 3 Zonation prioritization results for an example area from our study region. Zonation priorities are shown for the *ecologically optimized* (A) and *integrated* (B) analyses (the *ecologically optimized excluding negative landowners* priorities are not shown, see in Annex C). (C) The numbered polygons (1–4) indicate forest estates for which we had data on landowner perceptions. (D) The trade-offs in conservation value between the three analyses. Conservation value as viewed by Zonation is the mean of the quantity of unprotected habitat values for each habitat type, here a composite index of tree age and volume: $\sqrt{(age \times vol)}$ (Annex C). Note that the large proportion of high-quality forest retained in the priority site is due to high variation in forest quality across the region, from clear-cuts to old growth forests.

stakeholders, such as forest management associations and nature enthusiasts.

Discussion

A great societal opportunity related to implementing voluntary biodiversity conservation initiatives is integration of various types of knowledge (social, ecological, scientific, and local) in the conservation planning processes for greater legitimacy and effectiveness. We contribute to such practice-relevant research agenda by integrating landowner perceptions and landscape level conservation values into a spatial prioritization, and deliberating the potential of prioritization to achieve improved conservation outcomes in the dialogue workshops.

In our case, prioritization that integrated ecological and social information produced an outcome that considerably reduced the loss in conservation value caused by potential conservation tensions or conflicts. To a certain degree, the observed influence depends on the assumptions made in the analysis. For example, we used relatively coarse habitat classifications with a Zonation variant that enabled any valuable site to be fairly easily replaced by another. All prioritization results are context-specific, and depend on the socioecological and institutional circumstances of the study area and the ways in which they are operationalized in the analysis (Pressey et al. 2013). Thus, of particular relevance is the transferability of the prioritization by interpreting the assumptions and results in collaboration with relevant stakeholders with the aim of engaging them in practical conservation targeting.

We aimed to get all private landowners in the prioritization area to respond to the questionnaire, but found the strategy far too resource-intensive. However, in our

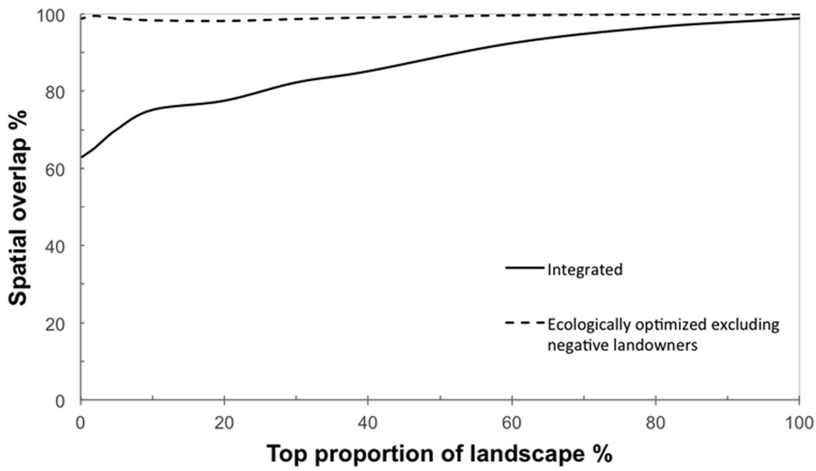

Figure 4 Spatial overlap (Jaccard's similarity index) of *integrated* and *ecologically optimized excluding negative landowners* solutions compared to *ecologically optimized* Zonation analysis. The solid line shows the overlap between the *ecologically optimized* and *integrated* solutions, and the dashed line shows the overlap between *ecologically optimized* and *ecologically optimized excluding negative landowners* solutions.

case the respondents did not differ significantly from the nonrespondents (Annex B), and thus the results should be regarded as illustrative, even though the magnitude of differences between different analyses may increase with more comprehensive data. We also complemented the dataset by focusing on sites with high conservation potential, where perceptions are most likely to have an impact on the prioritization outcomes. The strength of this spatially targeted dataset, even with its modest overall coverage, is the practical relevance of the prioritization outcomes: the research results are probably more relevant for conservation practice when selecting the most valuable sites for conservation than what could have been obtained with a similar sized random sample. Even quantitatively modest approaches might help progress the thinking and practice toward more socially minded prioritization.

Scaling up the prioritization to cover entire landscapes in multiple regions will require iteration and communication with planners, landowners and other relevant stakeholders. The dialogue workshops suggested that landowners and their advisers should be encouraged to collaborate more thoroughly in the prioritization process. For example, during field visits, the black box of prioritization could be opened by discussing the aim, analysis, and preliminary findings, thus involving landowners in iterating prioritization (Game et al. 2011) and developing ownership that supports future conservation collaboration. For practical implementation, we suggest that alternative prioritization analyses are produced and brought to regional stakeholder workshops, which would help determine the localities for targeted marketing of voluntary conservation by means of subsequent local meetings and personal communication. To be successful and cost-efficient, the phases should be conducted within existing policy processes and communicated transparently.

Our findings from the dialogue workshops support the idea that attitudes toward conservation evolve through social interaction (e.g., Bergseng & Vatn 2009), decreasing tensions attached to top-down, expert-driven conservation (Grantham et al. 2010; Winkel et al. 2015). Social learning through improved interaction could increase the acceptance of landscape-level conservation by two means: by changing individual attitudes and by changing shared perceptions of conservation within a social network (Cheng et al. 2011; Korhonen et al. 2013). Thus, in a specific area dialogue workshops might be a more accurate way to gather landowner perceptions than spending resources on numerous survey rounds or spatial nonresponse modeling. Even preliminary and incomplete prioritization analyses may be useful in such workshops.

Dialogue-based interpretation of prioritization can renew landscape-level targeting to a new level of integrative and inclusive conservation thinking (Tallis & Lubchenco 2014). However, certain institutional changes are required: the evolving technical tools and capacities go hand in hand with the opening and digitalization of data (Huijboom & Van den Broek 2011). In addition, landscape-level policy instruments that activate and provide financial incentives for cooperation between a number of landowners, such as agglomeration bonuses (Parkhurst et al. 2002) or multiscalar planning instruments (Kurttila & Pukkala 2003), are needed to support the change. Finally, education, leadership, and working resources are needed to support the change toward such adaptive management practices (Grantham et al. 2010).

Our results are applicable to many contexts where ecology-driven biodiversity conservation has faced resistance from stakeholders, or where the effectiveness of conservation has met challenges due to difficulties in designing and implementing high-quality conservation area networks, despite the general acceptance of conservation.

Acknowledgments

We would like to thank the Finnish Ministry of Agriculture and Forestry for funding the project and Iiro Ikonen, Maarit Jokinen, Sanna Kasurinen, Aija Kukkala, Mikko Kurttila, Leena Lehtomaa, Joona Lehtomäki, Marko Mäki-Hakola, Markus Nissinen, Outi Ratamäki, Sanna Tähtinen, and all the survey respondents and dialogue workshop participants for making the study possible in practice.

Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Annex A. Sampling of the survey and additional information about Factor Analysis in the Rekijokilaakso-Hyyppärä region.

Annex B. Differences between the respondents and nonrespondents of the survey.

Annex C. Material and methods used in Zonation prioritization analysis.

Annex D. Statements discussed in the dialogue workshops by the stakeholders.

References

Bazeley, P. & Jackson, K. (2013). *Qualitative data analysis with NVivo*, 2nd edn. SAGE Publications Ltd.

Berg, B.L. (2011). *Qualitative research methods for the social sciences*, 4th edn. Allyn and Bacon, Boston, MA.

Bergseng, E. & Vatn, A. (2009). Why protection of biodiversity creates conflict—some evidence from the Nordic countries. *J. For. Econ.*, **15**, 147-165.

Cheng, A.S., Danks, C. & Allred, S.R. (2011). The role of social and policy learning in changing forest governance: an examination of community-based forestry initiatives in the U.S. *For. Policy Econ.*, **13**, 89-96.

Doremus, H. (2003). A policy portfolio approach to biodiversity protection on private lands. *Environ. Sci. Policy*, **6**, 217-232.

Game, E.T., Lipsett-Moore, G., Hamilton, R., *et al.* (2011). Informed opportunism for conservation planning in the Solomon Islands. *Conserv. Lett.*, **4**, 38-46.

Gorsuch, R.L. (1988). Exploratory factor analysis. In J.R. Nesselroade, R.B. Cattell, editors. *Handbook of multivariate experimental psychology*, 2nd edn. Springer US, Boston, MA.

Government of Finland (2014). *Finnish Government Resolution on the continuation of Forest Biodiversity Programme for Southern Finland 2014–2025. [in Finnish]*. Finland.

Grantham, H.S., Bode, M., McDonald-Madden, E., Game, E.T., Knight, A.T. & Possingham, H.P. (2010). Effective conservation planning requires learning and adaptation. *Front. Ecol. Environ.*, **8**, 431-437.

Huijboom, N. & Van den Broek, T. (2011). Open data: an international comparison of strategies. *Eur. J. ePractice*, **12**, 4-16.

Jenkins, C.N. & Joppa, L. (2009). Expansion of the global terrestrial protected area system. *Biol. Conserv.*, **142**, 2166-2174.

Klein, C.J., Tulloch, V.J., Halpern, B.S., *et al.* (2013). Tradeoffs in marine reserve design: habitat condition, representation, and socioeconomic costs. *Conserv. Lett.*, **6**, 324-332.

Knight, A.T., Grantham, H.S., Smith, R.J., McGregor, G.K., Possingham, H.P. & Cowling, R.M. (2011). Land managers' willingness-to-sell defines conservation opportunity for protected area expansion. *Biol. Conserv.*, **144**, 2623-2630.

Korhonen, K., Hujala, T. & Kurttila, M. (2013). Diffusion of voluntary protection among family forest owners: decision process and success factors. *For. Policy Econ.*, **26**, 82-90.

Kurttila, M. & Pukkala, T. (2003). Combining holding-level economic goals with spatial landscape-level goals in the planning of multiple ownership forestry. *Landsc. Ecol.*, **18**, 529-541.

Lehtomäki, J., Tomppo, E., Kuokkanen, P., Hanski, I. & Moilanen, A. (2009). Applying spatial conservation prioritization software and high-resolution GIS data to a national-scale study in forest conservation. *For. Ecol. Manage.*, **258**, 2439-2449.

Mayer, A.L. & Tikka, P.M. (2006). Biodiversity conservation incentive programs for privately owned forests. *Environ. Sci. Policy*, **9**, 614-625.

Mickwitz, P. (2003). A framework for evaluating environmental policy instruments: context and key concepts. *Evaluation*, **9**, 415–436.

Moilanen, A., Arponen, A., Stokland, J.N. & Cabeza, M. (2009). Assessing replacement cost of conservation areas: how does habitat loss influence priorities? *Biol. Conserv.*, **142**, 575-585.

Moilanen, A., Pouzols, F.M., Meller, L., Veach, V., Arponen, A., Leppänen, J. & Kujala, H. (2014). *Spatial conservation* *planning methods and sofware Zonation Version 4 User Manual*. C-BIG Conservation Biology Informatics Group, University of Helsinki, Finland. Helsinki. Available from http://cbig.it.helsinki.fi/files/zonation/zonation_manual_v4_0.pdf. Accessed 17 January 2017.

Mönkkönen, M., Ylisirniö, A.-L. & Hämäläinen, T. (2009). Ecological efficiency of voluntary conservation of boreal-forest biodiversity. *Conserv. Biol.*, **23**, 339-347.

Paloniemi, R. & Tikka, P.M. (2008). Ecological and social aspects of biodiversity conservation on private lands. *Environ. Sci. Policy*, **11**, 336-346.

Paloniemi, R. & Vainio, A. (2011). Legitimacy and empowerment: combining two conceptual approaches for explaining forest owners' willingness to cooperate in nature conservation. *J. Integr. Environ. Sci.*, **8**, 123-138.

Parkhurst, G.M., Shogren, J.F., Bastian, C., Kivi, P., Donner, J. & Smith, R.B.W. (2002). Agglomeration bonus: an incentive mechanism to reunite fragmented habitat for biodiversity conservation. *Ecol. Econ.*, **41**, 305-328.

Peltola, A. (2014). *Finnish statistic yearbook of forestry 2014*. Available at: www.metla.fi/julkaisut/metsatilastollinenvsk/. Tammerprint Oy, Tampere.

Pressey, R.L., Mills, M., Weeks, R. & Day, J.C. (2013). The plan of the day: managing the dynamic transition from regional conservation designs to local conservation actions. *Biol. Conserv.*, **166**, 155-169.

Primmer, E., Paloniemi, R., Similä, J. & Tainio, A. (2014). Forest owner perceptions of institutions and voluntary contracting for biodiversity conservation: not crowding out but staying out. *Ecol. Econ.*, **103**, 1-10.

Salomaa, A., Paloniemi, R., Hujala, T., Rantala, S., Arponen, A. & Niemelä, J. (2016). The use of knowledge in evidence-informed voluntary conservation of Finnish forests. *For. Policy Econ.*, **73**, 90-98.

Le Saout, S., Hoffmann, M., Shi, Y., *et al.* (2013). Conservation. Protected areas and effective biodiversity conservation. *Science*, **342**, 803-805.

Selinske, M.J., Coetzee, J., Purnell, K. & Knight, A.T. (2015). Understanding the motivations, satisfaction, and retention of landowners in private land conservation programs. *Conserv. Lett.*, **8**, 282-289.

Tallis, H. & Lubchenco, J. (2014). Working together: a call for inclusive conservation. *Nature*, **515**, 27–28.

Tittensor, D.P., Walpole, M., Hill, S.L.L., *et al.* (2014). A mid-term analysis of progress toward international biodiversity targets. *Science*, **346**, 241-244.

Tomppo, E. (2006). The Finnish multisource national forest inventory: small-area estimation and map production. In A. Kangas, M. Maltamo, editors. *Forest inventory methods and applications*. Springer, The Netherlands.

Vainio, M., Kekäläinen, H., Alanen, A. & Pykälä, J. (2001). *Traditional rural biotopes in Finland. Final report of the nationwide inventory*. Finnish Environment Institute. Series 527, Vammala.

Whitehead, A.L., Kujala, H., Ives, C.D., *et al.* (2014). Integrating biological and social values when prioritizing places for biodiversity conservation. *Conserv. Biol.*, **28**, 992-1003.

Winkel, G., Blondet, M., Borrass, L., *et al.* (2015). The implementation of Natura 2000 in forests: a trans- and interdisciplinary assessment of challenges and choices. *Environ. Sci. Policy*, **52**, 23-32.

Annex A. Sampling of the survey and additional information about Factor Analysis in the Rekijokilaakso-Hyyppärä region.

The table below presents how the sampling of the survey was designed. Landowners from various regions replied to a postal questionnaire exploring various aspects of biodiversity conservation at landscape level. The way the respondents were selected in the different regions varied based on the information needs of the study and previous conservation history in the region. After receiving the responses and preliminarily analyzing the data, we realized the limitations of using the data set in the spatial analysis. In order to achieve better spatial coverage for Zonation prioritization analysis within one specific region (Rekijokilaakso-Hyyppärä) where total sampling was used, we complemented the data (this complementing effort is described *in Italics* in the Table) by calling a number of landowners who had not responded to the initial survey. We selected Rekijokilaakso-Hyyppärä for the spatial analysis because the ecological data that we needed for the prioritization analysis was most readily available there due to the systematic conservation efforts by regional nature conservation administration during the last decades. When complementing the dataset in Rekijokilaakso-Hyyppärä, we did not aim at a full or random sample, but purposefully focused on high-priority forests, as they have the potential to be protected, and on their “social” unavailability i.e. the owners’ negative attitudes that would have a negative impact on opportunities to design an ecologically sound conservation network. In low priority areas, landowner perspectives are irrelevant as the forests would not be protected anyway due to not meeting the ecological threshold criteria of the Forest Biodiversity Program. The population in the Pirkanmaa sub-sample was 8 952 forest owners, in the Central Ostrobothnia subsample 3 701 forest owners, and in the Northern Karelia random sample 2 7031 forest owners.

Region	**Sampling method**	**Number of sent questionnaires**	**Number of returned questionnaires (proportion of sent questionnaires)**
Rekijokilaakso-Hyyppärä	Total sample: every forest owner in the selected geographical area *Efforts to complete the sample by calling selected landowners who owned the most valuable sites (based on the Zonation analysis) or whose holdings were located next to the forest owners with a positive perception on cross-boundary conservation efforts (based on the Exploratory Factor Analysis). Note: in the complemented sample, we asked only the questions that we used in the factor analysis.*	679 *50*	112 (16%) *32*
Pirkanmaa	Random sampling of members of two subjectively selected forest management associations Excluding forest holdings smaller than 4 hectares.	296	64 (21%)
Central Ostrobothnia	Random sampling of members of two subjectively selected forest management associations Excluding forest holdings smaller than 4 hectares.	206	32 (16%)
Northern Karelia	Random sampling in the region Total sampling including: (ii) all forest owners who have a private conservation area contract (iii) all forest owners who have a forest	420 599 267 332	103 (25%) 195 (33%) 86 (32%) 109 (33%)

	environmental management contract signed in 2004-2013. Excluding forest holdings smaller than 2 hectares.	[The region total: 1019]	[298 (29%)]
	Questionnaires returned without an identification		3
Total:		**2 200**	**509** (23%) ***541*** (25%) *including the phone interviews in Rekijokilaakso-Hyyppärä*

The responses in the Completed Data Set (541 responses, of which 144 from the Rekijokilaakso-Hyyppärä region) were analyzed using Maximum Likelihood as the extraction method and Varimax with Kaiser Normalization as the rotation method (rotation converged in 6 iterations). Results explained 68% of the total variance among the original variables. The KMO measure of sampling adequacy = 0.801; Bartlett's test of Sphericity: $x^2 = 2312$; $p < 0.001$. Table 1 presents the rotated factor matrix (rotation converged in 6 iterations).

Note: Factor Analysis is a statistical method used to identify the underlying relationships (i.e. latent variables called factors) between measured variables (evaluated statements in our case); the Exploratory Factor Analysis is conducted without a priori hypothesis about the factors (which is the procedure in Confirmatory Factor Analysis).

The figures in Table 1 represent loadings of each statement (rows) on each latent meaning variable (columns); statements with loadings > 0.4 (in bold) constitute the main meanings of respective factors and are therefore discussed in the results. The sixth factor, *Just a contract,* only includes one statement and is not considered an actual factor. Respondents' scores for the first factor, *Cross-boundary conservation efforts* is used in Zonation analyses, because it appears to contain in single and operable variable relevant information on the forest owner's propensity to voluntarily join the ecological network of conservation areas within the neighborhood.

Annex B. Differences between the respondents and non-respondents of the survey. Based on the material we received from Forest Centre's database of forest estates, we analyzed whether those forest owners who responded to our questionnaire differed statistically significantly from those who did not respond in terms of social-demographic variables, forest property, and possible activity related to forest use.

Age (years)

We found a statistically significant difference between the mean age of respondents and non-respondents, the former being older than the latter:

	N	*Mean*	*Std. Deviation*	*Std. Error Mean*	*Significant / non-significant difference; 2-tailed T-test*
Respondents	93	63.2	14.74	1.529	t(546)= 2.67; p= .008
Non-respondents	455	58.7	14.96	.701	

However, even though there is a statistically significant difference in the age of respondents (on average 63 years) and non-respondent (59 years) in our sample, we believe that it is reasonable to trust the data, because in our sample the difference between the age of respondents and non-respondent is only a few years and because both groups are on average over 55 years, which generally indicates a less positive attitude towards conservation than younger age (Uliczka et al. 2004).

Instead, no statistically significant difference between respondents and non-respondents was found in relation to sex, size of owned forests, area for all operationally planned harvestings 2006–2016, area for operationally planned final fellings 2006–2016, area for cost-share funded forest management operations, and average timber volume of the estate.

Sex:

		Female	*Male*	*Total*
Respondents	Count	23	70	93
	Expected Count	21.6	71.4	93.0
Non-respondents	Count	104	351	455
	Expected Count	105.4	349.6	455.0

Pearson Chi-Square =.15; p=.69

Forest holding size: (hectares of forestry land according to the Forest Centre's database):

	N	*Mean*	*Std. Deviation*	*Std. Error Mean*	*Significant / non-significant difference; 2-tailed T-test*
Respondents	93	10.95	13.91	1.443	t(548)= -1.70; p=.091
Non-respondents	455	14.44	18.82	.880	

Area (ha) for all operationally planned harvestings 2006-2016 from Forest-use declarations:

	N	*Mean*	*Std. Deviation*	*Std. Error Mean*	*Significant / non-significant difference; 2-tailed T-test*
Respondents	58	8.61	11.36	1.491	t(291)= -.840; p= .40
Non-respondents	235	10.10	12.33	.804	

Area (ha) for operationally planned final fellings 2006-2016 from Forest-use declarations:

	N	*Mean*	*Std. Deviation*	*Std. Error Mean*	*Significant / non-significant difference; 2-tailed T-test*
Respondents	40	3.22	4.80	.76	t(209)= -1.20; p= .24
Non-respondents	171	4.09	4.00	.31	

Average timber volume (m^3 per hectare):

	N	*Mean*	*Std. Deviation*	*Std. Error Mean*	*Significant / non-significant difference; 2-tailed T-test*
Respondents	92	151.16	151.16	8.19	t(532)= -.533; p= .594
Non-respondents	442	155.89	155.89	3.67	

Reference:

Uliczka, H., Angelstam, P., Jansson, G. & Bro, A. (2004). Non-industrial private forest owners' knowledge of and attitudes towards nature conservation. Scandinavian Journal of Forest Research 19: 274–288.

Annex C. Material and methods used in Zonation prioritization analysis

Material

The ecological data used in the analysis were chosen on the basis of their policy relevance in the ongoing Forest Biodiversity Program (Government of Finland 2014) where results from similar Zonation analyses are implemented in real world conservation planning. Those analyses have additionally taken advantage of more detailed but closed forest resources data that were not available to us (due to forest owner privacy reasons). Regional authorities and forest professionals use the Zonation maps in the evaluation and selection process of sites with potentially high conservation value as a basis for targeting landowner communication.

The ecological data were built by using the multi-source national forest inventory of Finland (MS-NFI). It consists of spatial predictions of the volume of growing stocks of trees for four tree species, stand age and fertility (Tomppo 2006). As in Lehtomäki et al. (2009) the forest data were divided into 20 features composed of four dominant tree species in five different productivity classes (Table C1). These raster map layers contained an estimate of local quality measured as $\sqrt{(age \times volume)}$, giving high value for locations with large volume of old trees. The traditional wooded rural biotope data were drawn from the Finnish National Survey and added as the 21st layer (Vainio et al. 2001). To transfer the scores of factor *Cross-boundary conservation efforts* into another layer, we retrieved coordinates for the land parcels of different land-owners from the national land register. Spatial data were prepared using ArcGIS 10.1 software.

We transformed all raw data into 60 m x 60 m resolution raster layers. Weights (Table C1) and connectivity parameters were assigned according to expert opinion to features in the MS-NFI data (modified based on Lehtomäki et al. 2009 for the purposes of regional nature conservation authorities as a part of Forest Biodiversity Program) and values in line with the forest layers were assigned to the traditional rural biotopes data.

Table (C1). Feature layers and their weights used in Zonation analysis.

Layer	Species group	Habitat type	Weight
1	Pine	Dry upland forest site	1.5
2	Pine	Vaccinium site type	1.5
3	Pine	Fresh mineral soil forest sites	1.5
4	Pine	Upland forests with grass-herb vegetation	1.5
5	Pine	Herb-rich forest	2.5
6	Spruce	Dry upland forest site	1.0
7	Spruce	Vaccinium site type	1.0
8	Spruce	Fresh mineral soil forest sites	2.0
9	Spruce	Upland forests with grass-herb vegetation	2.0
10	Spruce	Herb-rich forest	2.5
11	Birch	Dry upland forest site	2.0
12	Birch	Vaccinium site type	2.5
13	Birch	Fresh mineral soil forest sites	2.5
14	Birch	Upland forests with grass-herb vegetation	3.5
15	Birch	Herb-rich forest	5.0
16	Other broadleaves	Dry upland forest site	2.0
17	Other broadleaves	Vaccinium site type	3.0
18	Other broadleaves	Fresh mineral soil forest sites	4.0
19	Other broadleaves	Upland forests with grass-herb vegetation	5.0
20	Other broadleaves	Herb-rich forest	8.0
21	Wooded traditional biotopes	All habitat types	8.0

Methods

We used the Additive benefit function variant of Zonation, where the marginal value of a cell is determined by summing across all biodiversity features in it. It is considered most appropriate when the features are essentially surrogates for species, such as the habitat types in our study. The analyses were run with the Matrix connectivity feature, for which connectivity between partially similar habitat types was set according to expert opinion (Lehtomäki et al. 2009).

For the *Integrated* analysis the scores from the factor *Cross-boundary conservation efforts* were normalized and weighted six-fold between extreme attitudes towards conservation. All areas without factor scores (nonrespondents) were given a median score. Median score was selected following a precautionary principle, to build the network around areas that will be available for conservation with highest certainty. Overestimating positive conservation attitudes may cause the network to be built around areas that turn out unavailable when the results are used in practice. Technically, this layer was used as a Cost layer (Moilanen et al. 2014). Note that this does not imply that unwilling landowners could be convinced to conserve their property with higher compensation, but it is merely a technical solution that allows for weighting the sites differently, and hence increasing or decreasing their probability of being included or excluded in the highest priorities. Such a weighting has in principle a rather straightforward impact in Zonation (although additional considerations such as connectivity will influence the pattern to some extent): If the relative weight ("cost") of a high value site increases, it will drop somewhat lower down in the priority ranking, and conversely, positive perception and hence a lower weight will improve a site's ranking. The magnitude of this site weight was decided based on trial runs with different scales (raw factor scores, and weightings from 3-fold to 100-fold), and the one with acceptable compromise outcomes was chosen (the 6-fold weighting): With this scaling a site with moderately high conservation value could climb to the top fraction of the ranking (e.g. from top 20% to top 10%) due to having a positive perception, but a mediocre site would not become top priority only because of the landowner's positive perception.

For the *Ecologically optimized excluding negative landowners* analysis, we used the Solution load feature in Zonation that allows for examining prior ranking results with new settings and analysis options. Here we removed the areas of landowners with negative perceptions (values below median on the *Cross-boundary conservation efforts* factor, in total 3.5% of the area) from the analysis by using Analysis Area Mask. In practice, this solution was forced to follow identical cell removal order with the *Ecologically optimized* analysis in order to reveal differences based only on removal of sites with negative perception, simulating a planning process where land availability is not considered until at the implementation stage.

Quantitative differences between the three analyses were verified by Jaccard's similarity index with library "Zonator" in R v3.2.1 (R Development Core Team, 2011) (Figure 3).

Annex D. Statements discussed in the dialogue workshops by the stakeholders. The statements varied slightly in the different locations as they were modified according to locally relevant topics (in brackets).

[*E.g. Biodiversity conservation by management*] is the most important environmental target in [*e.g.Rekijokilaakso*]. The Forest Biodiversity Programme and the forest law bring additional value to the conservation of [*e.g., biodiversity of old-growth forests*] in [*e.g., Northern Carelia*]. People who implement The Forest Biodiversity Programme should regularly meet with researchers and they should negotiate the program targets together.
The Forest Biodiversity Programme has created co-benefits in addition to biodiversity conservation, for example, the acceptance of nature conservation has increased. The Forest Biodiversity Programme has improved or ruptured social relationships among different actors in the area. The Forest Biodiversity Programme advances satisfaction of forest owners with biodiversity conservation.
Nature-friendly forest management practices can have more positive effects on forest species than increasing conservation areas. In order to protect biodiversity at the landscape level, forest owners should try to find solutions together. Regional Forest Management Associations are closer to landowners than nature conservation authorities and therefore negotiate with landowners more smoothly.
The proportion of fixed-term contracts should be decreased for the benefit of permanent conservation contracts. Nature management projects improve the network of conserved areas if they are implemented near national parks or other valuable conserved areas.

Management actions, even if performed only once, can cause permanent improvement in biodiversity.
Forest could be cut in an agreed manner before permanent conservation of an area to save costs. When prioritizing conservation areas to the Forest Biodiversity Programme, ways of conserving the features of nature in a changing climate should be considered. Fixed-term conservation contracts are better than permanent contracts because they allow including new targets in nature conservation programs in the future.
When planning the Forest Biodiversity Programme, the amount of required information, advice and resources were anticipated better than in the Natura 2000 program. Future actions can be planned based on current knowledge in order to conserve biodiversity in the long run. The number of sites offered by forest owners and the resources to address demand are balanced at the annual level.
Forest-based livelihoods should be considered already in land use planning in order to combine different objectives. Other actors, in addition to landowners, perceive the Forest Biodiversity Programme to be fair and legitimate. Forest owners' initiative is essential to increase the acceptance of cross-boundary conservation planning.
Concepts that are relevant for conservation, like 'metapopulation' and 'connectivity' should be better explained in biodiversity advice. Knowledge on ecologically valuable sites on private lands belongs to all citizens and knowledge on, for example, the existence of [*species*], should be available publicly [if it doesn't threaten the protection of the species].

Signing a conservation contract in the Forest Biodiversity Programme or a nature management contract is convenient and the basis for compensation easy to understand.
Regionally important valuable areas should be evaluated systematically, for example with the Zonation program, to focus [*the Forest Biodiversity Programme /or marketing*] to valuable sites. Authorities should make conservation deals with all landowners in the same terms even if the nature values differ. Landowners' and nature enthusiasts' knowledge doesn't have enough impact on selection of conservation areas for the Forest Biodiversity Programme.